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RESEARCH ON PROBABLE MAXIMUM PRECIPITATION AND PROBABLE MAXIMUM FLOOD IN VU GIA – THU BON RIVER BASIN

Major: Hydrology
Code: 62 44 02 24

ABSTRACT OF Ph.D Dissertation

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The dissertation is completed at: **Vietnam Academy for Water Resources**

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At .....(hour), (date) in 2018

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INTRODUCTION

1. The necessity of the project

Over the last two decades, due to the negative effects of climate change, rain and flood have become more probable maximum. Rainfalls have high intensity and the total amount of rainfall reaches maximum level during the monitoring, which occur frequently, additionally, the basin is "degraded", so high flood flow and rapid accumulation of flood have been directly threatening to the safety of works and causing flood in the downstream. Many works, which were designed with the previous frequency, are no longer guaranteed in the current flood condition. Spillway opening of some reservoirs cannot release the actual flood peak discharge; operation procedure has not caught up with flood development yet, flood often threatens dam safety and causes consecutive floods in the downstream. In light of the facts, topic “Researching probable maximum precipitation, probable maximum flood in Vu Gia Thu Bon river basin” is chosen to evaluate the correlation between probable maximum rainfall, flood with calculated flood frequency in order to mitigate the potential risks to reservoirs and prevent floods in the downstream of Vu Gia Thu Bon river basin in particular and to become the premise for other studies on river basins in Vietnam in general.

2. Assignments of the dissertation

- Evaluating advantages and disadvantages of current PMP calculating methods in Vietnam, thereby improving the method of probable maximum rainfall determination in accordance with the tropical climate of Vietnam.
- Calculating PMP and PMF in Vu Gia-Thu Bon river basin, proposing a method to determine PMF quickly at these reservoirs, thereby recommending dam safety performance responding to PMF.

3. Subject and research scope

- Research scope: The entire Vu Gia-Thu Bon river basin, interaction between the upstream and downstream development conditions and flood, inundation in the river basin.
- Research subject: rainfall, heavy flood, probable maximum flood in Vu Gia-Thu Bon river basin.

4. Research methodology

The dissertation uses methods (i) Field survey; (ii) Statistical analysis; (iii) hydrologic and hydraulic modeling; (iv) Expert and participation of the community; (v) System analysis.

5. New contribution of dissertation

- Improving the method of probable maximum precipitation determination in accordance with the climate of Vietnam through the frequency coefficient K_{PMP}.
- Determining PMP, PMF in Vu Gia – Thu Bon river basin, thereby proposing a method to determine PMF quickly at reservoirs for dam safety control.

6. Structure of dissertation

The dissertation consists of 97 pages, 23 tables, 44 figures and 40 references. In addition to the introduction and conclusion, the dissertation consists of 3 following chapters:

Chapter 1: Overview of the study on probable maximum precipitation (PMP), probable maximum flood (PMF) in the world and in the country

Chapter 2: Scientific fundamental and practical of estimating Probable Maximum Precipitation and Flood

Chapter 3: Calculating PMP, PMF in Vu Gia – Thu Bon river basin

CHAPTER 1: OVERVIEW OF THE STUDY ON PROBABLE MAXIMUM PRECIPITATION (PMP), PROBABLE MAXIMUM FLOOD (PMF) IN THE WORLD AND IN THE COUNTRY

1.1. Definition

Probable Maximum Pricipitation: According to World Meteorological Organization (WMO, 1986), Probable Maximum Precipitation – PMP is *"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"*

Probable Maximum Flood-PMF: is the largest flood theoretically causing serious threats to flood control at a particular basin. This is a flood caused by a combination of the worst meteorological conditions occuring at a particular area.

1.2. Overview of studies on PMP, PMF

1.2.1. Studies on PMP:

The earliest study on PMP was made in 1950 in the United States, and studies on PMP have continuously developed. Myers, 1967 stated that PMP depends on humidity and wind speed bringing moisture into the basin.

Miller, 1963: Study on the relationship between precipitation and potential moisture of air mass has indicated two important points (i) the probable maximum precipitation can be estimated by saturated moisture at 1000hPa saturation vapor pressure of air mass and (ii) the maximum moisture of air mass can be estimated through the dew point.

Schreiner and Riedel, 1978: has successfully applied maximization method and displacement method to develop map of equal points of

PMP for duration from 6 hours to 72 hours in a large area in eastern US from the 1050th meridian.

Hansen et al., 1987: have studied and integrated impact of topographic features in PMP calculations which help to calculate accurately, reflecting the physical nature of terrain phenomena to the movement of moisture air masses.

Hershfield, 1961: proposed a new approach in PMP study. Accordingly, he considered the value of PMP as a statistical value of the observation serie, having a frequency relationship with other factors in following equation:

$$X_{PMP} = \bar{X}_m + K_{PMP}.S_m$$

Where: $\bar{X}_m$ and Sm are the mean and standard deviation for a series of m annual maximum rainfall values of a given duration at the location of calculation, Km is the frequency factor. In order to determine the coefficient of K_{PMP}, Hershfield analyzed more than 95.000 data at 2.645 rain gauge stations, among which 90% of stations are located in the United States and then he selected the largest value of Km which is 15 times larger than the value of K_{PMP}. In 1965, Hershfield has indicated that the value of Km can change depending on the rainfall period and the value of $\bar{X}_m$ (Hershfield, 1965). Since then, Hershfield has proposed that the value of Km can vary between 5 and 20 and it can be identified according to the empirical nomograph.

In Vietnam, there have been some studies and projects on PMP calculation since 1990. Especially, when the requirements for reservoir safety are increasing, PMF calculation is a necessary requirement for each important project. Many research institutes such as Water Resources University, Vietnam Academy for Water

Resources, Institute of Meteorology and Hydrology, Institute of Water Resources Planning and etc have studied PMP calculation to estimate PMF for hydraulic, hydropower structures in Vietnam.

Le Dinh Thanh (1996) has studied the application of PMP and PMF calculation in Vietnam. In this study, the author has studied methods of PMP calculation which are suitable for the tropical monsoon area, and then he has provided some remarks and suggestions for PMP-PMF calculation in Vietnam.

Do Cam Dam, Vu Kien Trung (2005) have studied PMP and PMF calculation in the Ministry-level project "Research on flood warning, forecasting and excessive design flood calculation in small and medium-sized reservoirs – solution of emergency spillway" according to statistical method.

Nguyen Van Lai and nnk (2009) calculated PMP for Trung Son hyrdopower according to 2 statistical methods and generalization. Then, authors use the Hec-HMS model to calculate PMF from PMP.

Pham Viet Tien (2007) calculated PMP for Ta Trach reservoir according to statistical method of Hershfield. PMP for Ta Trach catchment is the mean of values from Hue station and Nam Dong station. The author then uses the formula of Xocolopxki to calculate PMF for the river basin.

1.2.2. Studies on PMF:

In general, studies have indicated that PMF should be calculated from PMP. The main method for converting the probable maximum precipitation into the probable maximum flood is using rainfall-runoff model. Details on the selection of parameters and initial conditions of the model are presented in detail by United States Army Corps of Engineers (USACE, 1996). Some basic techniques

should be implemented. For example, the amount of damage due to seepage should be minimized, flood generation time should be as small as possible (based on actual data analysis) …

PMF has been studied in Vietnam initially since the early 1990s (Le Dinh Thanh, 1996), results from these studies have shown that $Q_{PMF} = 0,61 \div 1,71\ Q_{0,01\%}$.

Many studies on PMF calculation has been used for design calculation, inspection of a construction. For example, PMF calculation was implemented for Son La hydropower and Hoa Binh hydropower by Prof. Dr. Ngo Dinh Tuan. Assoc. Prof. Dr. Nguyen Van Lai năm 2004 has used various methods and determined that flood discharge of PMF for Trung Sơn reservoir in Thanh Hoa province varies between 27.012m^3 and 31.059m^3/s. Assoc. Prof. Dr. Le Dinh Thanh in 2004 calculted PMF for Phu Ninh rerservoir or other results of PMF calculation of Nguyen Quang Trung, Pham Viet Tien also contribute to the completion of database for river basins in Vietnam.

1.3. Gaps in PMF calcultion and the approach in PMF calculation of this dissertation

1.3.1. Gaps in PMF calculation

- Although values of PMP, PMF are insignificant at the 0.01 level, results of PMP and PMF calculation also depends greatly on the length of observed data series in the past (historical flood). In the context of global climate change, there are many values higher than observed historical values.
- Results of PMP and PMF calculation are significantly dependent on the subjective opinion of the calculator in the selection of a typical rainfall, selection of a frequency factor leading to the large difference in results of various authors for the same river basin.

- Vu Gia-Thu Bon river basin is the most vulnerable to flooding among river basins in the Central area which has been developing a network of upstream reservoirs. These reservoirs are currently designed according to frequency standard without being inspected by value of PMF.

1.3.2. The approach in PMF calculation of this dissertation

From gaps in PMF calculation in Vietnam, the dissertation will focus on analyzing the topographic characteristics, rainfall conditions of the river basin, pros and cons of the current methods of PMP, PMF to determine an appropriate method for the studied river basin according to the following diagram:

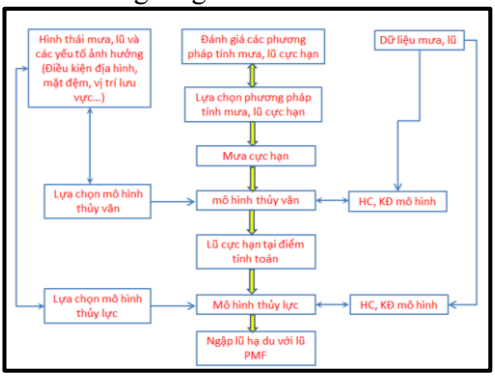

Figure 1.1: Diagram of an approach for PMP, PMF calculation in this dissertation

The selection of a method needs to meet following requirements:

- To be suitable for rainfall characteristics of the river basin, resolving problems due to impact of topographic conditions on distribution of PMP over time and space.
- To be suitable for large flood characteristics in the basin, taking into account the impact of topographic and landcover conditions on the flow of PMF at the outlet of the basin and at locations of interest.

1.4. Characteristics of Vu Gia-Thu Bon river basin

The Vu Gia-Thu Bon basin is bounded from 14°90' to 16°20' north latitude and 107°20' to 108°70' east longitude and its total area is 9,900 km^2 (excluding river basins of Cu De and Truong Giang rivers).

Figure 1.2: Administrative map of Vu Gia-Thu Bon river basin

Topography: 6,299 km^2, accounting for 64% of the basin area, is at the altitude over 300 m; 2902 km^2, accounting for 23% of the basin is at the altitude from + 10 m to + 300m. Area of 699km^2 with altitude lower than 10 m is located in the plain sub-basin.

River network: Vu Gia-Thu Bon river basin consists of two main rivers, Vu Gia and Thu Bon, whose flows are from the Ngoc Linh mountain of the Truong Son mountainous range in the North West to the South East. In the downstream area, two rivers exchange water dynamically with each other through the confluence and connected branches in a dense river network with complex hydrological and hydraulic condition. The Cai and Dakmi rivers flow from the upstream into Vu Gia river; Tranh and Khang rivers flow into Thu Bon river. In addition, Bung river and Con river are two tributaries of Vu Gia river at the confluence just after Thanh My Hydrological Station. The river bed slope is steep, ranges from 0.14 to 1.44% in the

upstream and about 0.02% in the downstream. These conditions lead to high intensity floods, occuring rapidly so that it is difficult for the management, response and reduction of damage caused by floods.

Infrastructure

Reservoirs for irrigation and hydropower: There are 72 reservoirs in Vu Gia-Thu Bon river basin with total capacity of over 150 million m^3, including 5 reservoirs with capacity of over 10 million m^3, 6 reservoirs with capacity from 1 to 10 million m^3, and other reservoirs with capacity under 1 million m^3. According to the statistic data, flood detention capacity of the large reservoirs is very small (41.44 million m^3) in comparison with total flood volume with frequency of 1%.

Traffic infrastructure: The local traffic network is convenient with 686 bridges across the river, 4 irrigation culverts, 4,957 kilometers of road and 75 kilometers of railways. According to the survey results in the rainy season, the traffic infrastructure causes inundation at many locations with high depth, especially in front of National Highway 1A, provincial roads 608, 607, 609.

CHAPTER 2: SCIENTIFIC FUNDAMENTAL AND PRACTICE OF ESTIMATING PROBABLE MAXIMUM PRECIPITATION AND FLOOD

2.1. Characteristics of big rain and flood in Vu Gia - Thu Bon basin

2.1.1. Annual rainfall distribution

Average annual rainfall in the Vu Gia-Thu Bon basin during 36 years (1976-2012) is 2,791 mm. Rainy season from September to December has a rainfall accounted for 70% of annual rainfall.

2.1.2. Characteristics of short-term rainfall

Relationship of Intensity – Duration – Frequency of rainfall (IDF)

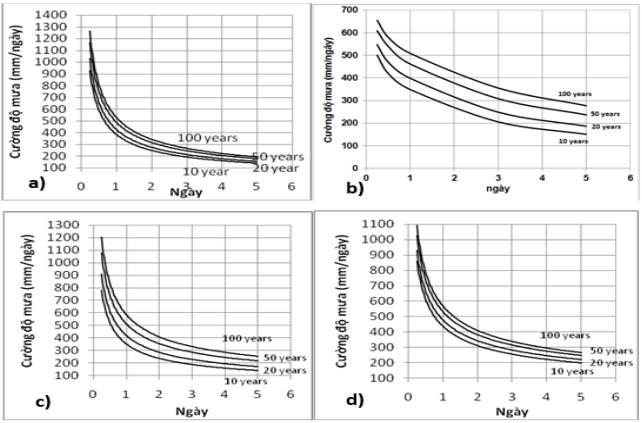

*Figure 2.1: **R**elationship of Intensity – Duration – Frequency of rainfall at meteorological stations*

a) Da Nang; b) Hien; c) Hoi An; d) Tra Mi.

The IDF at the stations shows that the intensity of rainfall at the frequency of 1% is higher than 500 mm/day and it is not much different between the meteorological stations. It is the consequence of the influence of the coastal area in combination with the narrow horizontal terrain of the basin.

- Rainfall intensity at the stations tends to increase slightly from the North to the South.
- Rainfall intensity decreases from the East to West.
- Diffusion of rainfall intensities with different frequencies in the South East is lower than in the North West.
- Gradient of IDF in the South East is higher than in the North West. It illustrates that short-term rainfall concentration in the South East is higher than in the North West.

Relationship of Depth – Area – Duration of rainfall (DAD)

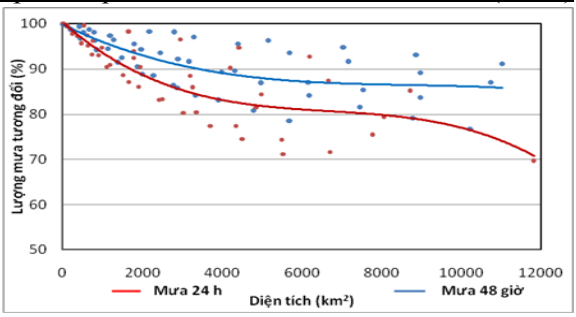

Figure 2.2: DAD curve of rainfall in 24 hours and 48 hours

The DAD curve above shows that difference of precipitation on an area of 10,000 km^2 in 24h and 48h is not so high as central precipitation location, 23% and 14%, respectively.

2.2. Method for estimating Probable Maximum Precipitation and Flood

2.2.1. Method for estimating Probable Maximum Precipitation PMP

Rainfall is influenced by many meteorological factors which fluctuate by time and space. Therefore, value of maximum precipitation is approximate and consistent with the monitoring data series. There are six main methods for estimating maximum precipitation, namely: i) Inferential method; ii) Local storm maximization method; iii) Generalized method; iv) Transposition method; v) Combination method; vi) Statistical method.

2.2.2. Method for estimating Probable Maximum Flood PMF

Historical flood method

Rare flood method: This method uses historical data in the basin or on a large continental or world wide area with an observation time of hundreds to thousands of years. Accordingly, this method will

attempt to develop a boundary of the biggest flood among observed values. Based on that boundary, value of PMF corresponding to each area of the study basin is estimated.

Estimation of PMF from PMP

This method is commonly used for converting volume of PMP to PMF. It applies the mathematical model of the rainfall-runoff process to estimate PMF from PMP.

2.3. Selection of method for estimating PMP, PMF in Vu Gia-Thu Bon basin

2.3.1. Method for estimating PMP

Meteorological and hydrographic data in the Vu Gia-Thu Bon basin are lack in many aspects and its time series is short. It is difficult to determine distribution of rainfall because the current rainfall monitoring stations are mainly located in the downstream areas but lack in the upstream. In addition, existing stations mainly monitor rainfall whereas other meteorological characteristics (wind, evaporation, dew-point temperature) are very limited. Therefore, it is not feasible to use research methods which require detailed data such as analysis, integration and generalization. Among the above six methods, the local storm maximization method and statistical method do not require long data series and allow to quickly determining the value of PMP with appropriate accuracy for comparing and checking. Some advantages and disadvantages of these two methods are as follows.

The advantage of the local storm maximization method is that it allows for a quick estimation of a PMP value in the region. However, it also has shortcomings to note for its application. First, value of PMP is only estimated at a local position so that it requires a dense

network of observed data points to estimate PMP for a large area or combination with some other methods. Secondly, estimated PMP is highly dependent on the length of the monitoring data series. If the maximum moisture as well as the maximum wind velocity is not collected, estimation of PMP is not realistic.

Advantage of the statistical method is using only rainfall data as a basis for calculation, so that it is suitable for many study areas. This method allows rapid estimation of PMP at any location with monitoring stations. However, estimation of PMP on a large area of the basin should combine different scaling methods because it only estimates PMP at points. On the other hand, previous studies used the frequency factor K_{PMP} referred to the nomographs which were developed by Hershfield from more than 6,000 rain gauges in the United States where the climate is temperate, with little variation in precipitation different from the tropics. Therefore, so the statistical correlation between the mean value and the frequency coefficient K_m should be validated to use in tropical regions such as Vietnam. In this dissertation, the statistical characteristics in the basins of Vietnam in general and Vu Gia-Thu Bon basin in particular are analyzed to apply this method to determine appropriate value of K_{PMP} to estimate PMP for Vu Gia-Thu Bon basin.

2.3.2. Method for estimating PMF

The data series for detailed modeling in Vu Gia - Thu Bon basin are still inadequate and limited. For example, there are not enough observation stations in the basin, not enough detailed geological, topographic maps ... so that the application of conceptual hydrological models is not applicable. Therefore, the unit flood model is used to estimate PMF of the study basin.

Based on the scientific practice, PMF is estimated at the outlet of the sub-basins and reservoirs. Flood is simulated in the basin with PMF. Its diagram is shown in the figure below.

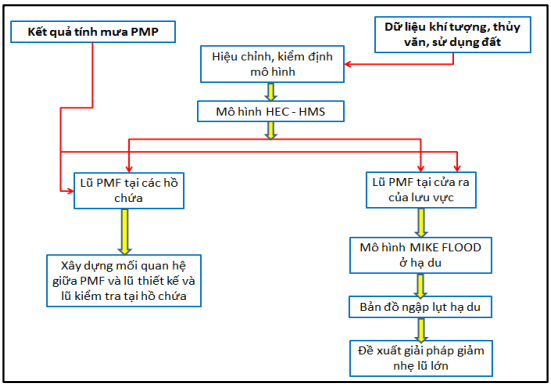

Figure 2.3: Diagram of PMF estimation and flood simulation in Vu Gia - Thu Bon basin

CHAPTER 3: CALCULATING PMP, PMF IN VU GIA-THU BON RIVER BASIN

3.1. Calculating probable maximum precipitation in Vu Gia-Thu Bon river basin

3.1.1. Statistical method

As analyzed in Chapter II, the most important step in calculating PMP by statistical method is determining the value of K_{PMP} which is appropriate to the studied river basin. In Vietnam, previous studies mostly use values of K_{PMP} given in Hershfield nomograph. After researching and analyzing this issue, the author has indicated that using these K_{PMP} values is not appropriate in terms of statistic because river basins in Vietnam are located in tropical climate area, there are different causes of rainfall compared to temperate climate area of the United States.

To be specific, some studies in Malaysia's river basins also has the value of K_{PMP} = 8 (L.M. Sidek, 2013) which is appropriate to its area instead of the value at 14 in Hersfiled's index. The study of B.Ghahraman in 2008 had the value of K_{PMP} = 9,63 which is appropriate to Antrak river basin of Iran instead of the value at 11 in Hersfiled's index. Therefore, purpose of this study is to determine the value of K_{PMP}, a representative for river basins in Vietnam.

In order to determine the value of Km, this dissertation has analyzed the maximum daily precipitation value from data series of 328 rain gauge stations throught the country which have the observed duration from 15 years and more.

The result of calculation has shown that most of K_m values are in the range of 2÷6, the mean is 4. Especially, when considering the observed data series in stations in Vu Gia – Thu Bon river basin, the maximum K_m value is only 6,4 in Hoi An station. If this value of Km as the vlue of $K_{PMP,}$ the maximum daily rainfall in all monitoring sites in the basin is less than 1.000mm. This value is very small compared to the ability of rainfall generation in the basin.

Table 3.1: Distribution of frequency value - Km

No.	K_m	Number of stations
1	1-2	6
2	2-3	89
3	3-4	103
4	4-5	65
5	5-6	27
6	6-7	17
7	7-8	7
8	8-9	7
9	9-10	4
10	10-11	2
11	11-12	1
12	>12	0

Therefore, in order to maximize the value of Km to become the value of K_{PMP}, the author plans to maximize the Km value of the data series. Based on the result of distribution of K_m values which are calculated above, the author uses Generlized extreme value distribution (GEV) to determine the non-degenerate maximum frequency value of K_m values as can be seen from Figure 3.1 below. As a result, the propability for K_m to be larger than 11 is very small, in other words, K_m=11 can be considered as the highest value in Vietnam. Therefore, using this value for calculating PMP of Vu Gia-Thu Bon river basin is appropriate to climatic conditions in the basin.

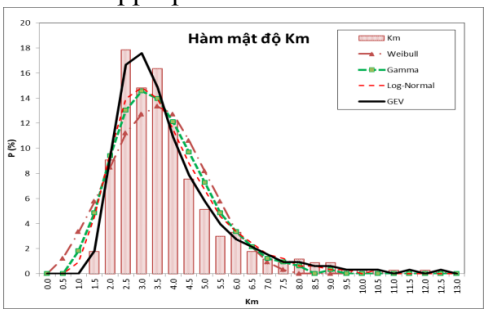

Figure 3.1: Histogram of the probability distribution of K_m values

Using the value of K_{PMP} = 11, we have the result of PMP at stations in table 3.2.

Table 3.2: PMP values at monitoring stations in Vu Gia-Thu Bon river basin

No.	Monitoring station	X_{1max}	X_{tb}	S_n	PMP_1 day	X_{1max}/X_{PMP}
1	Ai Nghia	501	230	87,7	1194	0.42
2	Cam Le	595	227	98,6	1312	0.45
3	Cau Lau	542	211	77,6	1063	0.51
4	Da Nang	593	224	91,5	1231	0.48
5	Giao Thuy	481	227	82,9	1139	0.42
6	Hien (Trao)	482	194	107,4	1375	0.35

No.	Monitoring station	X_{1max}	X_{tb}	S_n	$PMP_{1\ day}$	X_{1max}/X_{PMP}
7	Hiep Duc	527	239	82,0	1141	0.46
8	Hoi An	667	221	100,1	1322	0.50
9	Hoi Khach	459	211	96,7	1274	0.36
10	Tien Phuoc	534	279	96,5	1341	0.40
11	Kham Duc	531	249	98,5	1332	0.40
12	Nong Son	513	247	82,0	1148	0.45
13	Tra My	504	298	97,9	1375	0.37
14	Que Son	527	251	89,0	1230	0.43
15	Tam Ky	405	245	91,5	1252	0.32
16	Thanh My	622	202	107,0	1379	0.45
17	**Mean**	**530**	**235**	**93**	**1257**	**0.42**

3.1.2. Calculating PMP by maximizing method

Based on the data series observed at all rain gauge stations in Vu Gia-Thu Bon river basin, the author selected the rainfall from 01-08 November, 1999 as the historic rainfall. The rainfall in that year occurred on the large scale; the amount of rainfall at most of stations reached the historic value of monitoring series.

From rainfall data and meteorological characteristics (wind, dew-pont temperature) observed at stations, the author calculated PMP at stations in Vu Gia – Thu Bon river basin as follows:

Table 3.3: The value of correction factor K_{hc}, PMP at monitoring stations

No.	Rainfall station	Daily precipitation max (mm)	Correction Factor (K_{hc})	Daily precipitation PMP (mm)
1	Ai Nghia	501	3,44	1723
2	Cam Le	595	2,47	1470
3	Cau Lau	542	3,72	2016
4	Da Nang	593	2,15	1275
5	Giao Thuy	481	3,67	1765

No.	Rainfall station	Daily precipitation max (mm)	Correction Factor (K_{hc})	Daily precipitation PMP (mm)
6	Hien	482	4,05	1952
7	Hiep Duc	527	4,79	2524
8	Hoi An	667	3,75	2501
9	Hoi Khach	459	3,98	1827
10	Tien Phuoc	534	4,94	2638
11	Kham Duc	531	4,82	2559
12	Nong Son	513	4,30	2206
13	Tra My	504	6,34	3195
14	Que Son	527	4,46	2350
15	Tam Ky	405	4,73	1916
16	Thanh My	622	4,17	2594
Mean		**530**		**2157**

3.1.3. Selecting the value of PMP to be suitable for Vu Gia-Thu Bon river basin

Results of PMP calculation using two methods: statistical method and rainfall maximizing method have showed a large difference. If the PMP value is 1.257mm by statistical method, the PMP value is 1855mm by maximizing method, which is 48% higher than the PMP value by statistical method.

PMP values at stations in the Vu Gia-Thu Bon river basin when measured by the maximizing method show a large variation between 1275 mm in Da Nang to 3195 mm in Tra My, so the difference is 150%. Meanwhile, when calculated by statistical method, the difference is small, only varying from 1063mm at Cau Lau station to 1379mm at Hien station, so the difference is only 30%. Therefore, if the overall monitoring data series at stations are taken into account, the PMP value calculated by the statistical method is more suitabile. Along the coast of Vu Gia-Thu Bon river basin, the PMP values are calculated by the statistical method quite similar, ranging from 1231mm at Da Nang station to 1322mm at Hoi An station. This

result is consistent with the same cause of rainfall generation along this coast. Meanwhile, if the value of PMP along the coast is calculated by the maximizing method, it varies significantly from 1275mm to 2501mm. This is not in line with reality.

From above analysis, the dissertation selects the value of PMP by statistical method. The values of PMP at stations are quite similar, the ratio between the observed largest daily rainfall and the value of PMP ranges between 0,32 and 0,51. This is a reasonable value, which is consistent with a lot of results studied in the world such as the range is 0,39 – 0,72 in Malaysia.

3.2. Calculating probble maximum flood (PMF) in Vu Gia – Thu Bon river basin

3.2.1. Selecting simulation models for Vu Gia-Thu Bon river basin

Selected models are: (i) HEC-HMS model is selected for hydrologic calculation; (ii) MIKE 11, MIKE 21 and MIKE FLOOD models are selected for hydraulic calculation, the flood flow in the basin.

3.2.2. Results of calculation

Option 1: In the case of one-day PMP, PMF at Nong Son and Thanh My stations has a peak, PMF flood peak at Nong Son station is 32,142 m3/s and that at Thanh My station is 17,206 m3/s (Figure 3.2).

Option 2: Calculating PMF with the amount of 3-day PMP simulating flood development in 2009. The result has shown that the amount of PMF at Nong Son and Thanh My stations are 35.232 m3/s and 21.435 m3/s respectively (Figure 3.3).

Option 3: Calculating PMF with 5-day PMP simulating flood development in 1999. The result has shown that the amount of PMF at Nong Son and Thanh My stations are 29.578 m^3/s and 14.221 m^3/s respectively (Figure 3.4).

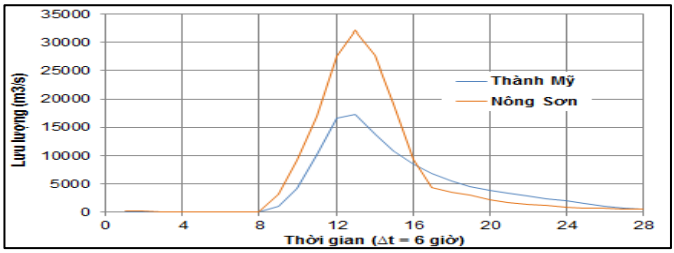

Figure 3.2: PMF flood flow at Thanh My and Nong Son with one-day PMP

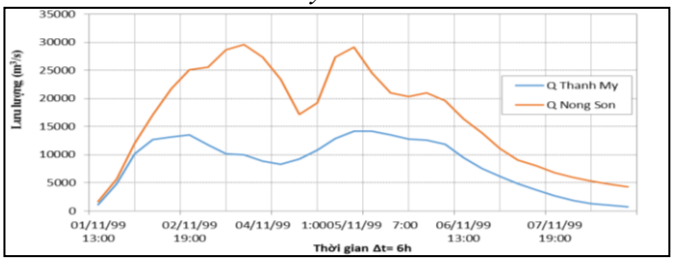

Figure 3.3 PMF flood flow at Thanh My and Nong Son with flood development in 1999

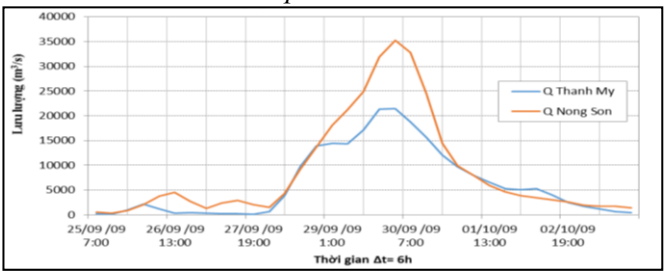

Figure 3.4: PMF flood flow at Thanh My and Nong Son with flood development in 2009

The results of PMF peak flow calculation at dams of reservoirs have shown that design flood peak flow and observed flood peak flow at reservoirs are smaller than that of PMF.

The results have shown that if PMF occurs in these reservoirs, the safety of works cannot be guaranteed. Therefore, the modification of planning/design, the safety inspection for new works in line with the PMF standard is necessary. However, calculating PMF flood peak

with a series of steps requires the assurance of scientific and technical requirements. Given the observed data series are insufficient in terms of time and space in Vietnam, the determination of this value is very difficult and not always determinable, especially in small and medium-sized reservoirs where there are no meteorological and hydrological monitoring stations.

Based on the results of PMF peak flow in reservoirs in Vu Gia-Thu Bon basin, the dissertation develops a table to edit the flood peak flow according to the design frequencies equal to the value of PMF peak flow. In order to ensure the safety of the design work as a priority, the corrected value shall be taken as the upper line of the relationship between repeatability (design frequency) and the ratio of the design frequency flow/observed flow at works with corresponding PMF value.

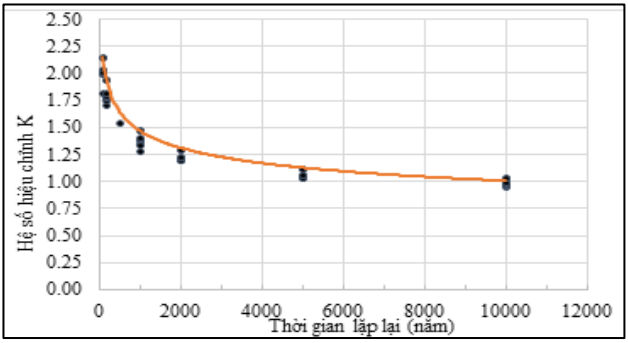

Figure 3.5: The graph of K_{hc} corrected by repeatability at reservoirs

Figure 3.5 shows that for small design frequencies (large repeatability), the value of the correction factor K_{hc} is small and vice versa. Specifically, for a repeatability of 100 years, the correction factor is 2.15, while for a repeatability of 5000 years, the correction value is only 1.11. Based on the relationship graph, K_{hc} values can be determined for different design frequencies.

Although the relatiohip graph is based on only a few observed, calculated data, it will help to quickly identify PMF values at

necessary locations in the basin. This relationship will be more valuable when calculating, gathering a large amount of data, not only in Vu Gia - Thu Bon basin but also in adjacent basins.

3.3. Inundation level in the downstream corresponding to PMF flood event

Using the models established in the dissertation, with PMF flood calculated according to the duration of 1999, the inundation process in the downstream is simulated with the results as below:

a) Area, inundation level of the downstream area

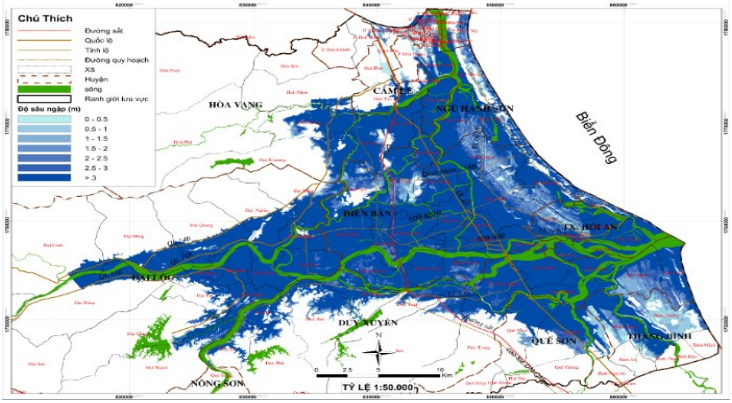

Figure 3.6: Inundation map of the downstream area corresponding to PMF flood event

The simulation results with PMF flood event shows that 74% of total area has been inundated, in which the area with the flood depth above 3m is upto 500 km^2 equivalent to 55% the area of the downstream (Fig 3.6). With such a large area and depth of inundation, there is almost no resillience ability and no where to evacuate people, lost of life and property is unpredictable.

b) Distribution of inundation area in the downstream

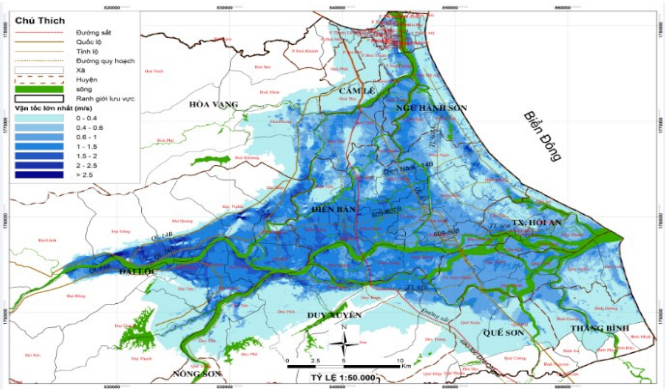

Figure 3.7: Flood velocity map of the downstream area

Large velocity will destroy the infrastructure and facilities of people in the floodplain. The simulation results show that, when a PMF flood occurs, the flow velocity in the floodplain can reach up to 2.5 m/s. This flood velocity is very high and will cause seriously damage to people and property in the flood areas.

3.3. Proposing solutions for large flood mitigation

3.3.1. Solutions for PMF flood management

According to calculation results, the PMF precipitation occurs relatively uniform in the basin, so the ability (theoretically) PMF flood will occur on a large scale too. It's impossible to effectively respond. In this case, the thesis will propose the following solutions:

1. Upgrade the safety of reservoirs by calculating checking flood with PMF flood, upgrade, expand the spillway for quick flood drainage.
2. Upgrade the quality of short term and medium term forecasting, strengthening communication and warning as soon as possible.

3.3.2. Solutions for large flood management

a. Non-structural solutions

1. Raise knowledge about natural disaster prevention.

2. Firmly and strictly comply with regulations on flood calculation, flood discharge of reservoirs in the basin for timely response.
3. Improve the flood forecasting quality
4. Protect watershed forests.

b. Structural solutions

1. Select a suitable method of improving the quality of the structure
2. Follow activities of structures which can occur incidents
3. Organize timely response to the incidents.
4. Follow possible incidents in both side of the river: landslide, cracked, causing dangerous, organize to evacuate people to safety places…

CONCLUSION

Flood risk management is always a pressing issue for every country due to its importance in the sustainable socio-economic development and environmental safety of a basin. Particularly in the context of intensive climate change with extreme storm and flood in recent years, the study on great floods and effective flood management is an urgent issue.

By studying PMP and PMF estimation methods in accordance with the rainfall characteristics of the watershed, the author has chosen the appropriate method of estimating maximum precipitation in the study basin, as well as the HEC-HMS hydrologic model, MIKE 11, MIKE FLOOD hydraulic models to estimate flood and inundation in Vu Gia-Thu Bon basin.

According to the study, the application of statistical methods is supposed to be more reliable than other methods under the current data condition of Vietnam. It also estimates that PMP is usually two to three times higher than the maximum rainfall observed. Average PMP of the basin is 1257 mm, tends to distribute evenly throughout the catchment; the highest rainfall of 1379 mm and the lowest

rainfall of 1063 mm are not different significantly. Accordingly, if PMP occurs across the basin, PMF at the Nong Son station on Thu Bon river and Thanh My station on Vu Gia river reach flood peaks of 35,232 m3/s. and 21,435 m3/s.

Because the simultaneous occurrence of PMP and PMF is a hypothetical scenario, which hardly happens in reality, PMF simulation is only developed in researching condition which is not considerable in developing practical flood mitigation and management. Therefore, PMF is applied for rapid estimation of specification in designing reservoirs by establishing a relationship between design flood and PMF of the sub-basin. It would be applicable for design of reservoirs with different capacities.

LIST OF PUBLICATIONS

1.Dương Quốc Huy, (2016), *Đánh giá xác định giá trị mưa cực hạn cho lưu vực Vu Gia-Thu Bồn*, Tạp chí Khoa học và Công nghệ Thủy lợi, Viện Khoa học Thủy lợi Việt Nam.

2.Dương Quốc Huy, Nguyễn Văn Duy, Ngô Lê Long, Nguyễn Tùng Phong, (2016), *Ứng dụng mô hình toán xây dựng bản đồ ngập lụt hạ du lưu vực sông Vu Gia-Thu Bồn,* Tuyển tập hội nghị Khoa học thường niên Trường Đại học Thủy lợi.

3.Dương Quốc Huy, Ngô Lê Long, Ngô Lê An, Dương Thúy Hường, (2016), *Nghiên cứu tính toán lũ cực hạn (PMF) lưu vực sông Vu Gia-Thu Bồn,* Tuyển tập hội nghị Khoa học thường niên Trường Đại học Thủy lợi.

4.Dương Quốc Huy, Nguyễn Văn Duy, Nguyễn Thanh Hiền, (2015), *Analysing characteristics of rainfall and flood in Vu Gia-Thu Bon river basin,* Viet Nam-Japan Workshop on Estuaries, Coasts and Rivers 2015, Construction Publishing House.

5.Dương Quốc Huy, Nguyễn Tùng Phong, Ngô Lê Long (2014), *Applying generalized extreme value distribution statistical function for estimating probable maximum precipitation in Vu Gia-Thu Bon river basin*, The 11th INWEPF Steering Meeting and Symposium. Vietnam Water Resources University.

6.Dương Quốc Huy, Nguyễn Tùng Phong, Ngô Lê Long, Ngô Lê An, (2013), *Giới thiệu một số phương pháp tính mưa lớn nhất khả năng PMP,* Tạp chí Khoa học và Công nghệ Thủy lợi, Viện Khoa học Thủy lợi Việt Nam.