ESTIMATION OF PROBABLE MAXIMUM FLOOD (PMF): A CASE STUDY OF POTHWAR REGION, PAKISTAN.

[*]Muhammad Waseem Boota[1], Ghulam Nabi[1], Tanveer Abbas[1]
Muhammad Yaseen[1], Muhammad Faisal [1], and Muhammad Imran Azam[1]
[1]Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Address Lahore, Pakistan.
*****Corresponding Author's email: engr.waseemboota@gmail.com

ABSTRACT: *This paper demonstrate a method to compute the Probable maximum flood (PMF) for a Pothwar region used for hydrological estimation to ensure the safety of dam. Design floods for dams in Pothwar region is based on the probable maximum flood (PMF) which results from the probable maximum precipitation (PMP) using statistical approach involving Hershfield, Gumble and Log Pearson Type- III distribution. The PMF is defined as the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions. The method used to determine the probable maximum flood is deterministic approach, which uses PMP as the meteorological input. The deterministic method of estimation of PMF consists of the transformation of the PMP with a rainfall-runoff deterministic model into a runoff hydrograph. For the hydrologic modeling studies the new version of HEC-HMS hydrologic modeling software was used in study to estimate the PMF. The inputs of the model in determination of PMF are the sub-basin physical parameters such as area and the length of the stream, reach parameters, reservoir parameters, meteorological parameters and ishoyetal map of PMF were estimated by using the ARC-GIS tool. As a result of model application studies, infiltration loss and base flow parameters of each sub basin are calibrated. Time of concentration (tc) and Lag time was estimated using the Kirpich formula. PMF was estimated in khanpur dam to be 152, 147 Cumecs, and HEC-HMS model was calibrated at khanpur and other stations.*

***Keywords*:** Probable Maximum Flood (PMF), Hydrological model; Isohyetal Map, Dam Safety

INTRODUCTION

The PMF is by definition the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study. A PMF is generated by the probable maximum precipitation (PMP), which is defined as theoretically, the greatest depth of precipitation for a given duration that is physically possible for a given size storm area at a particular geographic location at a certain time of year. The purpose of the study was to calculate PMF for Pothwar region and to assure flood safety in study area. The 24-hours data of rainfall was used to estimate the PMP and this PMP is used to estimate the PMF.

The benefits of dams are numerous such as flood mitigation, domestic and industrial water supplies, hydropower generation, irrigation and it also create lake for recreation and fishing. However, dams pose risk to communities in the downstream area if not designed, operated and maintained properly. With the increasing value of safety, especially in developed and developing countries, dams have been recognized as latent hazards. This makes it necessary to put extra effort in ensuring the safety of dams throughout the dam's life cycle. Thus, existing dams and reservoirs should be reanalyzed periodically to ensure that they still meet the test of safety by current standard, seeing that knowledge of hydrology, seismicity, and the geological environment accumulates, and technology advances, facilities once regarded as safe may need modifications.

PMF also has physical meanings which provide an upper limit of the interval within the engineer must operate and design. Today, the Probable Maximum Flood (PMF) is generally accepted as the standard for the safety design of dams where the incremental consequences of failure have been determined to be intolerable. Therefore, there is a need to do a hydrological analysis of Pothwar region catchment to evaluate the risk of overtopping. The estimation and prediction of extreme floods is a central theme in hydrologic engineering and dam safety by Swain et al., [16]. Mathematical watershed models are used to describe or simulate extreme floods.

The watershed models that are extensively used to simulate extreme floods and Probable Maximum Floods (PMFs) are, in most cases, unit hydrograph or storage routing models. In the United States, the HEC-1 [4] and HEC-HMS models [10]. (HEC, 2006) are used by the Corps of Engineers, and the Flood Hydrograph and Runoff (FHAR) model [8] is used by the Bureau of Reclamation. These models based on unit hydrographs are used nearly exclusively for dam safety. In the United Kingdom, the national flood guidelines specify the use of a unit hydrograph model for extreme flood runoff and PMF calculations [11]. Similarly, the Australian Rainfall-Runoff guidelines for extreme flood estimation, published in 1987, have been revised [1].They recommend using unit hydrograph or storage routing models such as RORB by Laurenson et al., [13]. There are numerous studies done using HEC-HMS such as evaluation of Rainfall-Runoff in Southern California and a study of spillway adequacy and dam break analysis of Ka Loko Dam, Hawaii in 2007. For the evaluation of rainfall-runoff in Southern California, two previously-calibrated HEC-HMS models were used to predict runoff characteristics under a variety of climatic conditions and impervious coverage reduction scenarios. The HEC-HMS modeling framework was specifically chosen for this study because of its ability to accurately represent the flashy nature of Santa Barbara area meteorological conditions.

For the Ka Loko dam break analysis, HEC-HMS together with HEC-RAS is chosen to determine downstream inundation areas resulting from dam failure. HEC-HMS is the best choice to compute rainfall-runoff at each hydraulic component in large basins and behaves better in pure channels with short culvert lengths while HEC-RAS is run for hydraulics [10]. Basically, there are two methods to determine the PMF. The first one is to use the PMP estimate using rainfall-runoff models, which involves many assumptions about the PMP, including the conditions of the catchment and physical features for its upper bound. Due to the methods used in developing safety evaluation flood estimates, the criteria based on PMP and PMF estimates are termed as deterministic approach. The other method is known as probabilistic approach applied on either floods or rainfall, which have specified probabilities or average return periods.

DESCRIPTION OF STUDY AREA

General

The Pothwar region of Punjab, Pakistan area selected for the estimation of PMP. It borders with the western parts of Azad Kashmir and the southern parts of Khyber Pakhtunkhwa. Pothwar region covers the northern part of Punjab with districts of Chakwal, Attock, Jhelum, Khoshab, Mianwali and Rawalpindi. The Pothwar terrain has flat to gently undulating terrain, broken by gullies and low hills/ranges as shown in Fig. 1.

The annual rainfall usually varies from 500 to 1000 mm. More than seventy percent of annual precipitation in Pothwar region is almost received in the months of July and August (monsoon season), and the tropical depression comes from the bay of Bangal as shown in Fig 2 (a, b). Main causes of water erosion in this area is due to undulating topography and high intensity monsoon rainfall. Pothwar region consist of an area more than one million hectares lie in latitude 32° 10 to 34° 9 N and longitude 71°10 to 73°55 E with an of elevation of 350 to 575m .

Pothwar Plateau is surrounded on the east by the Jhelum River, west by the Indus River, north by the Kala Chitta Range and Margalla Hills, South by the Salt Range. The soil texture of the Pothwar region is different; loess, mixed material, alluvial and colluvial in nature and it is derived from sandstone and shale. Pothwar region is classified as sub-humid and sub-tropical climate.

METHODOLOGY

Description of the Hydrological Model

In this study, the deterministic approach was chosen in determination of PMF for the Pothwar region. The HEC-HMS software developed by the US Army Corps was used in the study area. It is hydrologic modeling software developed by US Army Corps of Engineers Hydrologic Engineering Center.

It includes many of the well-known and well applicable hydrologic methods to be used to simulate rainfall-runoff processes in river basins [15]. This approach attempts to represent the most severe combination of meteorological and hydrological conditions considered reasonably possible for a given drainage basin. PMP is used as meteorological input.

In PMF for the Pothwar region, Curve number, length of the channel, highest and lowest elevation, slope was estimated using the ARC-GIS tool. Synder's UH method was used to model, the direct runoff and constant monthly for the base flow method. In addition, Lag method was used to model the routing. As for calibration process for Pothwar case study, Khanpur dam was selected. The objective of calibration is to determine the most suitable value of Ct and Cp of Synder's UH

method. The basin lag, tp was calculated by using the Kirpich formula.

$$T_c = 0.00032\, L^{0.77} / S^{0.385} \qquad (1)$$

Where; "Tc" is the time of concentration (hours), "L" is maximum length of water travel (m), S is the surface slope, given by H/L (m/m)

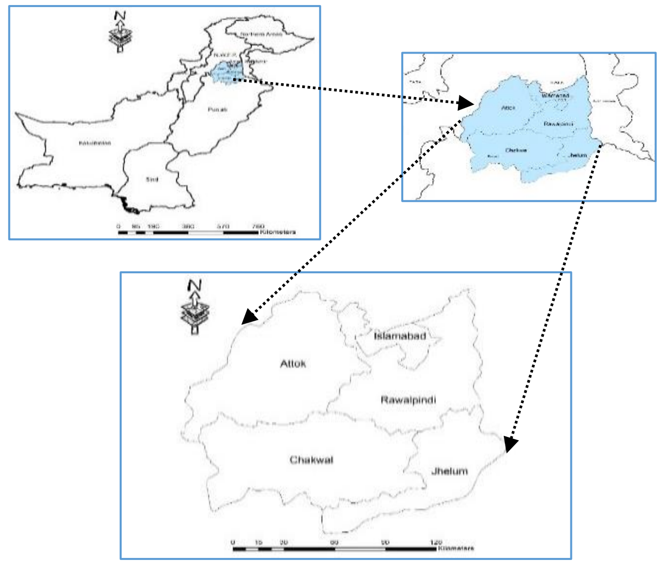

Fig 1: Map of Study Area

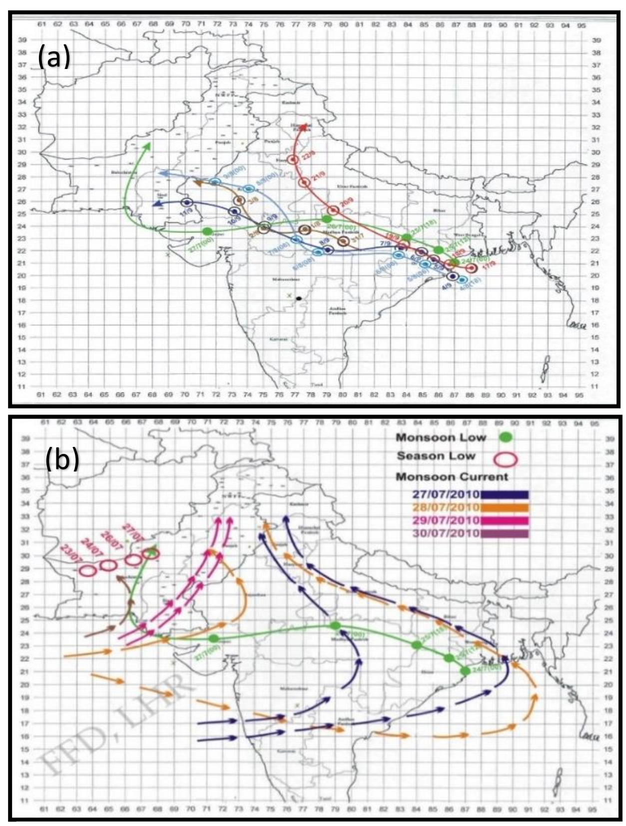

Fig 2 (a) Tracks of monsoon lows during flood season 2010 (b) Tracks of monsoon low super flood 2010, moisture incursion and position of seasonal low.

Time of concentration (tc) is defined as the time required for an entire watershed to contribute to runoff at the point of interest for hydraulic design; this time is calculated as the time for runoff to flow from the most hydraulically remote point of the drainage area to the point under investigation. Travel time and tc are functions of length and velocity for a particular watercourse. A long but steep flow path with a high velocity may actually have a shorter travel time than a short but relatively flat flow path. There may be multiple paths to consider in determining the longest travel time. The designer must identify the flow path along which the longest travel time is likely to occur. After this the probable maximum flood (PMF) and peak discharge at different return periods were also calculated by using the PMP value.

RESULTS AND DISCUSSION

ESTIMATION OF THE PMF AT THE DAM SITE

Three basic methods were used in this study. The first three methods such as flood frequency analysis, rational method and IUH using storm profile was used for estimating the PMP. This PMP value was used to estimate the PMF, Runoff was calculated by using the means of equation (2) the unit hydrograph method, and equation (3) the Rational method, respectively. Estimation of the PMP was achieved by using the transposition and in situ maximization of historic storms over the period 1880-1982 [10]. The storm rainfall was maximized according to the following method:

$$M_{rain} = (Mpw/Spw)\ R \qquad (2)$$

Where; “R” is the storm rainfall, “Mpw” is the maximum perceptible water at the time of the storm, “Spw” is the perceptible water of the storm and “Mrain” is the maximized rain. The third method estimates the PMF from the annual maximum flood series by using the modified Gumbel scale and probability weighted regression. In this scale the relationship:

$$\text{Log } Y_t = a \log T + c \qquad (3)$$

Where; “T” is the return period and “Yt” is the reduced variate. In using these methods, consistency in the result is important, but where consistency is not as high as is desired, reasons for the discrepancies should be determined if a single design figure is to be credible. Furthermore, due regard should be given to future changes in land use and climatic variability, which may not have been adequately sampled in the data set on severe storm.

ISOHYETAL MAP OF POTHWAR REGION

The Isoheytal map of PMP and PMF constructed in Pothwar region by using the Arc-GIS tool. The Isohyetal maps of PMP, PMF, Peak maximum rainfall (mm) and Runoff (m^3/sec) were constructed are shown in Figures 3 and Figures 4 (a, b, c, d).

APPLICATION OF PMP TO KHANPUR DAM AND CALIBRATION OF MODEL

Khanpur Dam project derives its name from the village khanpur located at 8 miles North of Texila on Haripur road and about 25 miles from Islamabad, the Capital of Pakistan. The catchment covers area of 308 sq. miles with a Gross reservoir capacity of 107,076 acre feet with a maximum flood anticipated 182000 cusecs. The estimated flood in this catchment is 152, 147 Cumec and observed flood in this catchment found to be 182,200 Cumec shown in Table 1. Table 1 also represents the PMF values of study area and this PMF varies from 1110 to 5882 Cumec. The maximum peak flow was estimated at different return periods for the stations of Gujjar Khan, Kallar Syedan, Murree, Chirah Bridge and Chawkal sites which is also shown in Table 3. The HEC-HMS model is also calibrated at the Khanpur dam and the results is also shown in the Table 2.

It is estimated the 1-day PMP for the Pothwar region, which varies from 150 mm to 320 mm shown in Fig. 3 (b), and the PMF were estimated from this value of PMP. The results shows that the PMF varies from 1,110 Cumec to 3813.52 Cumec as shown in Fig. 3 (e), similarly peak flow at 20, 50 and 100 return period was observed to be 541.17 to 3664.62 Cumec shown in Fig.3 (a, c, d). In this manuscript we present the PMF results obtained using the hydrological model with a non-uniformly spatially and temporally distributed precipitation of PMP type. Table 2 shows the different parameters such as curve number, highest elevation, lowest elevation, length of the channel, slope, time of concentration (t_c) and lag time of different catchment. Table 3 Shows the PMP and PMF at different return period and application of PMP in khanpur dam. Similarly, the curve number (CN) value calculated for the study area varies within 70 to 90. A duration of one day is based on the observed time to peak of severe floods in the area [14]. The storm profile was based on the severe rainstorms which have occurred in the area [15] and the IUH method was used to estimate the PMF. Table 1 show the results where a value of 4509 Cumec is given. The same storm data are also used in the Rational equation which gives a slightly lower result.

Table 1: Comparison of PMF Estimated from Different Methods

Flood frequency analysis	4280
Rational Method	4320
IUH using storm profile	4509

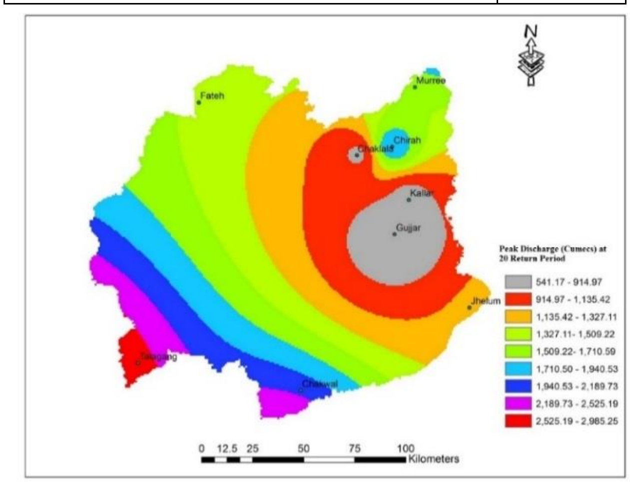

Figure 3 (a): Spatial Distribution of Peak Discharge (Cumec) at 20 Year Return Period

Table 2: Different Parameters of the Study Area

Sr. No	Catchment	Area (Km2)	Curve No	Highest Elevation (m)	Lowest Elevation (m)	Length of Channel (m)	Slope	Time of Concentration (hrs)	Lag Time (min)
1	Jhelum	1600	77.36	334	280	71000	0.000761	27.63	995
2	Gujjar Khan	1945	71.37	490	460	59000	0.000508	27.98	1007
3	Kallar Syedan	930	76.85	540	470	49000	0.001429	16.29	586
4	Chirah Bridge	811	73.68	630	470	30000	0.005333	6.72	242
5	Murree	796.67	80.00	1700	750	35000	0.027143	4.05	146
6	Chaklala	1200	79.11	710	430	56000	0.005000	11.15	401
7	Fateh Jhang	5400	78.58	430	370	87000	0.000690	33.55	1208
8	Chakwal	4044	81.84	406	195	98000	0.002153	23.72	854
9	Talagangh	5697	80.05	780	356	101000	0.004198	18.78	676

Table 2: PMF and Peak Discharge (Cumecs) at Different Return Periods in Study Area

Sr. No	Catchment	PMP (mm)	Max. Rainfall (mm) at different Return Period			PMF (Cusecs)	Max. Discharge (Cusecs) at different Return Period		
		Max	20	50	100	Max	100	50	20
1	Jhelum	281	178	209	232	2327.4	1773.5	1518	1240
2	Gujjar Khan	175	121	138	150	1110	796	690	541
3	Kallar Syedan	200	154	178	197	1182.4	1157	999.7	803
4	Chirah Bridge	230	227	205	175	2724.2	2679.7	2360	1924.9
5	Murree	320	211	245	271	4280	3592	3248	2791
6	Chaklala	250	194	225	248	54332	51806	43772	2303
7	Fateh Jhang	190	149	164	184	3088.5	2780	2120	1530
8	Chakwal	179	142	156	168	3789.5	3198	2930	2594.1
9	Talagangh	170	139	153	165	5882.8	4490	4130	3740.3

Application of PMP in Khanpur Dam

	Catchment	Area(Km^2)	Lag time (min)	PMF (Cumecs)	PMF (Cusecs)	PMF at Khanpur(Cusecs)
10	Khanpur	797.7	249.21	4280	152,147	182,200

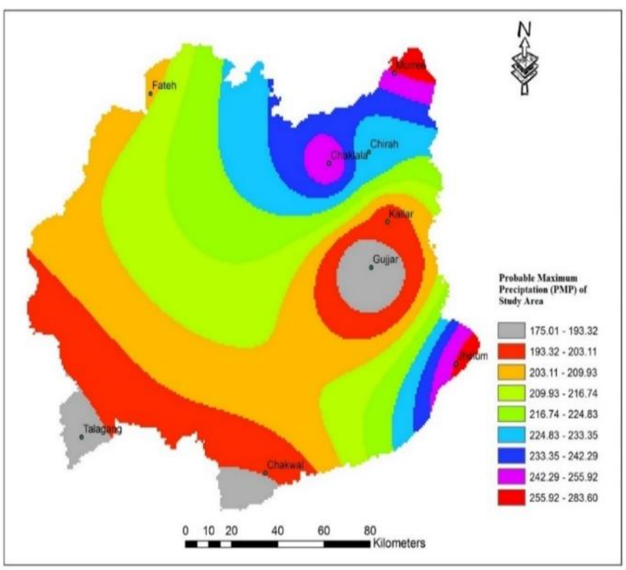

Figure 3 (b): Spatial Distrubtion of PMP at Study Area

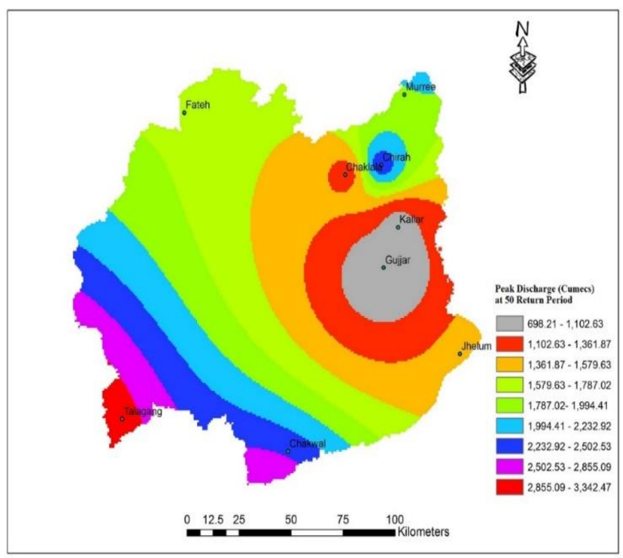

Figure 3 (c): Spatial Distrubtion of Peak Discharge (Cumecs) at 50 year Return Period

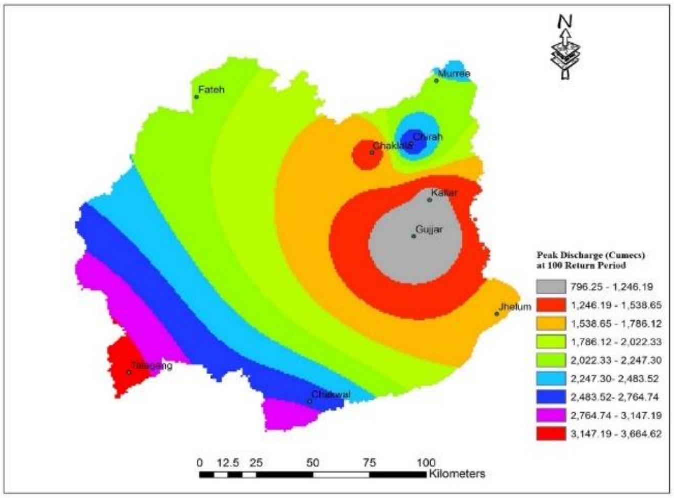

Figure 3 (d): Spatial Distrubtion of Discharge (Cumec) at 100 Year Return Periods

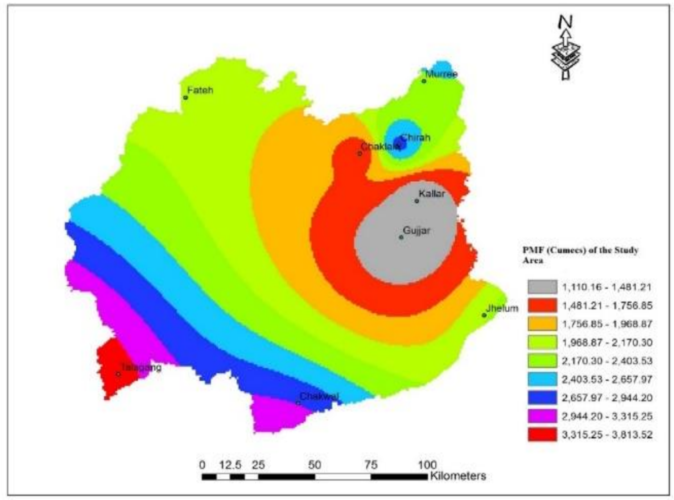

Figure 3(e): Spatial Distrubtion of PMF (Cumec) of Study Area

CONCLUSIONS

The continued increasing demand for water in Pakistan will mean that more dams will be built in the future. This study of the probable maximum flood (PMF) at Pothwar region has shown that the design floods have been seriously underestimated. The consequences for dam safety and the likely loss of life in the event of a major dam breach are severe. Although the estimates of the PMF are open to consideration and may be revised in the future, lack of knowledge of the long-term flood frequency means that assumptions have been made in the techniques used. In the future, with increasing intensity of land use, the rate of Runoff is likely to increase so that a degree of safety should always be incorporated into the design flood.

REFERENCES

[1]. Australian Rainfall and Runoff (ARR), 2001. “Volume One: A Guide to Flood Estimation (in eight books). The Institution of Engineers”, Australia.

[2]. Bureau of Reclamation (Reclamation), 1990. “Flood Hydrograph and Routing System (FHAR) Computer Model version 4.14”, Technical Service Center, Denver, CO.

[3]. Bureau of Reclamation (Reclamation), 2002. “Interim guidance for addressing the risk of extreme hydrologic events. Dam Safety Office and Technical Service Center, Denver”, CO, **3** p.

[4]. Center (HEC), 1998. “HEC-1 Flood Hydrograph Package, User’s Manual, CPD-1A, version 4.1. U.S. Army Corps of Engineers”, Davis, CA, **434** p.

[5]. C.R Neill & W.E. Watt. 2001. “Report on Six Case Studies of Flood Frequency Analyses”. Ontario: Alberta Transportation.

[6]. FEMA. 2004. “Selecting and Accommodating Inflow design Floods for Dams”. New York: Federal Guidelines for Dam Safety.

[7]. F. Frances & B.A Botero. 1994. “Probable Maximum Flood Estimation Using Systematic and Non-Systematic Information”. **Stochastic Hydrology and Hydraulics. Volume 12(4)**, 267 – 283.

[8]. Flood Hydrology Group, Technical Service Center. 2004. “PMF Hydrograph of San Joaquin River New Dam at River Mile 286”. California: US. Department of Interior.

[9]. Hydrologic Engineering Center (HEC), 2001. “Hydrologic Modeling System HEC-HMS User’s Manual, Davis CA”: Hydrologic Engineering Center Hydrologic Engineering.

[10]. Hydrologic Engineering Center (HEC), 2006. “Hydrologic Modeling System HECHMS, User’s Manual, CPD-74A, version 3.0.1. U.S. Army Corps of Engineers”, Davis, CA, 248.

[11]. Institute of Hydrology (IH), 1999. “Flood Estimation Handbook (FEH) – Procedures for Flood Frequency Estimation (in five volumes). Institute of Hydrology”, Wallingford, Oxford shire, United Kingdom.

[12]. Mark S. Woodbury, Douglas T. Eberlain & Nicholas Pansic. 1994. “Minimizing the Probable Maximum Flood”. Inform Global Magazine: 64.

[13]. World Meteorological Organization (WMO) , 1045. Manual of Estimation of Probable Maximum Precipitation (PMP)

[14]. Robert B. Jansen. 1983. “Dams and Public Safety. Denver: A Water Resources Technical Publication”, U.S Department of the Interior.

[15]. Robert E. Swain, David Bowles & Dean Ostenaa. 1998. “A Framework of Characterization of Extreme Floods for Dam Safety Risk Assessments”. Proc. USCOLD Annual Lecture (August 1998), Buffalo, New York.