THE PROBABALE MAXIMUM FLOOD AT NIRA-DEOGHAR DAM SITE IN INDIA

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ABSTRACT

Estimation of inflow design flood i.e. Probable maximum flood (PMF) for major storage reservoirs is most important parameter. The consequences of a failure of the structure due to improper estimation of PMF could be calamitous in terms of loss of human lives and damage to property. PMF which is estimated from probable maximum precipitation (PMP) is used as inflow design flood for major projects. PMP is the greatest depth of precipitation for a given duration which is physically possible for an area. Various methods such as statistical, empirical, storm maximisation and transposition approach, and dynamic approach are used for estimation of PMP. This paper presents unit hydrograph method which reflects all physical characteristics of the catchment for obtaining PMF hydrograph. The study area selected is Nira-Deoghar dam which is located on River Nira in the Krishna basin, Maharashtra, India. The outcome of PMF in Indian scenario is very much important since it is directly related to dam safety.

Keywords: Dam safety, Probable Maximum Flood, Probable Maximum Precipitation, Instantaneous Unit Hydrograph.

1. INTRODUCTION

A high-consequence dam is a large dam whose failure would have large consequences to life and/or property downstream. The magnitudes of extreme floods and their associated annual exceedance probabilities (AEP) are necessary to ensure that such a dam is safe. Traditionally, the largest "physically possible" precipitation event (the Probable Maximum Precipitation, PMP) and its associated flood event (the Probable Maximum Flood, PMF) have been calculated with a combination of statistical and meteorological techniques (Bingeman , 2001) .
The probable maximum flood (PMF) derived from the probable Probable maximum precipitation (PMP) is the basic design flood for spillways of large dams (Rakhecha,et al,1985, Wang et.al 1986, Hansen,1987, Fernando et al, 2011).
According to WMO (2009), Probable Maximum Precipitation (PMP) is the theoretical maximum precipitation for a given duration under modern meteorological conditions. Such a precipitation is likely to happen over a design watershed, or a storm area of a given size, at a certain time of year. Use of PMP to generate PMF has become the standard for dam design in many parts of the world including United States, China, India, Australia, (Douglas, et al, 2003,Fernando et al, 2011). Prior to 1950s, the concept was known as maximum possible precipitation (MPP). The name was changed to PMP reflecting the uncertainty surrounding any estimate of maximum precipitation (Wang 1984).
The concept of PMP is based on the assumptions that a) there exists an upper physical limit of the precipitation depth over a given area at a particular geographical location at a certain time of year and b) that this limit can be estimated based on deterministic considerations (Papalexiou, et,al,2006).

During the period of 1920-40, there developed a concept of a PMF, which means the greatest flood that ever could be experienced on a given stream by reasons of limitations of the drainage area, channel (or rather valley) capacity, rates of inflow of warm air, precipitation, snowmelt and other meteorologic, hydrologic and hydraulic elements that operate to produce a flood(Mutreja,1986).

2. LITERATURE REVIEW OF PMP AND PMF

The concept of 'probable maximum precipitation' (PMP) originated in the mid-1930s as 'maximum possible precipitation' (MPP) with the assumption that a maximum limit exists for precipitation over a drainage basin (Stallings et al, 1986, Fernando, 2011). Myers (1967), Biswas (1971), Hansen (1987), Dubler et al (1996) have presented excellent historical developments in this field. The foundation for determining the level of PMP is the extreme storm record and the concept of storm maximization, transposition and envelopment. The practice in establishing the spillway design flood for high dams can be subdivided into four periods. These periods may be called the early period, the regional flood period, the storm transposition period, and the probable maximum precipitation period.

Rakhecha et al (1985) used generalized methods of calculating PMP for catchments of four large dams in India and demonstrated that the generalized tropical storm method of estimation of PMP can be used in India. The normalized values obtained by this method can then be applied to any individual catchment with the appropriate adjustment factors.
The transformation of PMP to PMF requires the estimation of retention losses, the derivation of unit hydrographs, the convolution of rainfall excess and unit hydrograph, the flood routing through the channel and reservoir and selection of antecedent and subsequent floods. Various Methods are available for transformation of PMP to PMF. Wang, et al(1986), presented number of case studies in which PMP estimates are transformed to PMF estimates depending on project and data situations. Use of PMP to generate PMF has become the standard for dam design in India. Rakhecha et al (1994) estimated PMP for stations in the north Indian region, north of 20^0N. For data available for 286 stations on the region, maximum annual 2-day rainfall data for an 80 year period, from 1901 was obtained. By using this data and using Hershfield method a mathematical relation between frequency factors (k_m) and mean annual extreme rainfall (X_n) was developed. By using this equation k_m are obtained for different values of X_n and subsequently 2-day PMP valu for 286 stations are estimated. Using these PMP estimates, a generalised chart was prepared, showing spatial distribution of 2-day PMP. The results indicate that the statistically estimated PMP rainfall can occur under optimum meteorological conditions. Similarly Rakhecha et al (1999, 2000,2002) used in situ maximisation and storm transposition approach for estimating PMP for a 1-day, 2-day and 3-day duration for different locations in India. The resultants obtained are considerably higher than those obtained using statistical analysis of daily rainfall records using Hershfield's method. Therefore implications of present studies for dam safety in India are serious. Similarly Rezacova et al (2005), Singh et al, (2014) described the technique used to estimate point and area PMP values over the Czeck territory and Jhalarapatan region of Rajasthan in India Respectively.
Shalaby A. I., (1995), designed an experiment to perform sensitivity analysis of the PMF to its contributing factors. The objective was to to develop set of guidelines for assessing the effects of causative factors on PMF. The proposed set of guidelines also eliminate the trial and error process in selecting factors to estimate the PMF thus minimising the chance of obtaining an inaccurate and under estimated value of PMF. This helps to compute optimum value of PMF.

Smith, (1998) pointed out that the term ‘reasonably possible’ in the definition of PMP is a purely qualitative verbal descriptor. It tells nothing about frequency of this event and hence may be interpreted differently by people. Any flood, including PMF, has some probability of occurrence. Hence in the paper it is pointed out that frequency can and must be assigned to the PMF. A method is suggested for estimation of the probability of PMF, and criteria are given for the level of societal risk that can be considered as acceptable. Because deficiencies in PMP estimates results in similar deficiency in PMF determination, Dawdy and Lettenmaier (1987) suggested a risk-based approach to hydraulic design criteria.

The PMP approach which practically assumes a physical upper bound of precipitation amount is contrary to the probabilistic approach. Koutsoyiannis (1999) proposed a simple alternative formulation of Hershfield’s statistical method for estimating PMP. Koutsoyiannis developed a straightforward method for assigning a return period to PMP values estimated using the frequency factor method.The application of the method can be improved when long series of local rainfall data are available that support an accurate estimation of the shape parameter of the Generalised Extreme Value (GEV) distribution. The alternative formulation assigns a probability distribution function to annual maximum rainfall, thus allowing for the estimation of risk either for the Hershfield’s PMP value or any other large rainfall amount. Papalexiou and Koutsoyiannis (2006) argued that Probabilistic approach is more consistent to the natural behaviour and provides better grounds for estimating extreme precipitation values for design purpose. Nobilis et al (1991) and Deshpande at el (2008) concluded that Statistical considerations concerning physical upper limits should always be considered for improving the input data for PMF studies.

Many studies have documented an upward temporal trend in the frequency and intensity of extreme precipitation events. There is a direct influence global warming on precipitation. There are reasons why warming could lead to increased PMP values (Trenberth,2011, Easterling et al,2011, Stratz, et al, 2014, Miguel et al., 2014, Afrooz et. Al, 2015). Kunkel et al (2013) used both climate model simulations and conceptual models of relevant meteorological systems to analyse climate change effects on PMP. The Climate model simulations indicate a substantial increase in water vapour concentrations which is principal input to PMP estimation techniques, thus indicating that PMP values will increase in the future and raise the risk of damaging floods. Jothityangkoon et al(2013), Beauchamp at el(2013) estimated the values of PMP under changed climate. In both the studies it is observed that PMP intensity increases by 0.5-6%.

Jothityangkoon et al(2013), estimated PMP value for Upper Ping River catchment based on statistical analysis, extrapolation, and transposition of observed precipitation and used catchment water balance model to estimate PMF. Beauchamp at el(2013), estimated PMP based on synthetic storm isohytal pattern analysis (WMO 1986) and applied HSAMI hydrologica model to simulate summer-fall PMF.

Salas et al (2014) examined the concepts and methods of estimating the PMP and PMF considering their associated uncertainties. The chapter discusses the uncertainty of the PMP and also presents detail procedure for estimating the uncertainty of the PMP based on Hershfield’s method. It also describes PMF estimation and uncertainty, which includes sensitivity analysis and Monte Carlo analysis, as well as some statistical alternatives. It is concluded that the values obtained for PMP which accounts for uncertainty are more than estimated values of PMP obtained by traditional Hershfield’s method.

The snow melt combined with specific weather conditions contribute to extreme floods, mainly during the spring. O’Connor et al (2004), acknowledged that snow may melt and contribute to extreme floods, and those contributions have been found in different countries in temperate regions.

Chen et al (2016), estimated PMF over three target watersheds in Northern California, based on historical storm events. They estimated PMF with physically based hydrological modeling system, the Watershed Environmental Hydrology (WEHY) model system. Statistical approach to PMF estimation does not explain how atmospheric variables other than precipitation, such as snowmelt, affect a flood. The numerical atmospheric-hydrologic modeling provided comprehensive physical approach that can explain not only the effect of precipitation, but also other atmospheric variables, such as air temperature and radiation, on maximum flood, as all these atmospheric variables evolve in time and space over target watershed.

3. METHODOLOGY

There are various methods available for transforming Probable Maximum Precipitation to Probable Maximum Flood.

3.1 Estimation of Probable Maximum Flood

For estimating of Probable Maximum Flood, Probable Maximum Precipitation unit hydrograph technique is used. The process of evaluating the PMF consists of the following steps;

3.1.1. Estimate duration of design storm

Duration of design storm equivalent to base period of unit hydrograph rounded to the next nearest value which is in multiplier of 24 hours and less than and equal to 72 hours is considered to be adequate. For large catchments, the storm duration for causing the PMF is to be equivalent to 2.5 times the travel time from the farthest point (time of concentration) to the site of the structure.

3.1.2. Selection of design storm

A design storm is an estimate of the rainfall amount and distribution over a particular drainage areas accepted for use in determining the design flood. This could either be the Probable Maximum Storm (PMF) or the Standard Project Storm (SPS).

3.1.3 Time adjustment of design storm and its critical sequencing

The design hyetograph should be arranged in two bells (peak) per day. The combination of the bell arrangement and the arrangement of the rainfall increments within each of the bell shaped spells will be representing the maximum flood producing characteristics.

The critical arrangement of increment in each bell should minimize the sudden hill or sluggishness and maximizing the flood peak. Hence, the arrangement is to be such that the time lay between peak intensities of two spells may be minimum. The cumulative pattern of all the increments in the order of their positioning should resemble the natural

Mass curve pattern as observed by a Self-Recording Rain gauge (SRRG) of the project region.

3.1.4. Estimate the design Unit Hydrograph

Depending upon the data availability and characteristics of flood hydrograph etc, the unit hydrograph may be derived using any of the following techniques.

1 Simple method of unit hydrograph derivation from a flood event with isolated peak

2 Collin’s method

3 Nash method

4 Clarke model.

In case of insufficient data, synthetic unit hydrograph may be derived

3.1.5. Calculating the probable maximum flood hydrograph
The critical time sequence of the design storm rainfall is superimposed on the derived design unit hydrograph to give the direct hydrograph, when added to the base flow, gives the probable maximum flood hydrograph.

4. CASE STUDY

4.1 Nira-Devghar Proje

In this paper Nira Deoghar catchment, one of the Sub-basin of Krisnha River is considered for the study.
4.1.1 Study area
Nira Deoghar dam is mainly an irrigation earthen dam; receive its main source of water from ghat area of Sahyadri hills. The Catchment area is predominantly influenced by North West Monsoon. The month of June to October accounts for major rainfall. Nira river is the tributary of of bhima river. The catchment area of project is 114.48 sq. km. The location plan of the dam is shown in figure 1.
In this case flood data is not available for deriving unit hydrograph. To overcome such difficulty, Nash has developed co-relation that exists between the IUH parameters n and k, and basin parameters like length of main stream, slope, area, etc.

Figure 1: Location Plan of Nira-Devghar Project.
(Source:- Google Images)

4.1.2 Salient Features

1. Name of Project ----- Nira-Devghar
2. Location ----- Devghar
3. River ----- Nira
4. Basin ----- Krishna
5. District ----- Pune
6. State ----- Maharashtra
7. Type of dam ------ Earthen
8.

4.1.3 Controlling Levels

1. River bed level ----- 611.975 meter
2. Sill level ----- 623.621 meter
3. Minimum Drawdown ----- 626.00 meter
4. Full reservoir level ----- 667.10 meter
5. Maximum water level ----- 667.50 meter
6. Top of dam level ----- 670.50 meter

5. RESULTS AND DISCUSSIONS

In this project PMF study was carried out by CDO, Nasik only with the similar methodology described earlier. The PMF hydrograph ordinates are obtained by and shown in table 1. The unit hydrograph ordinates (col. 2) and ordinates of rainfall excess (col. 3) are calculated first and these results are used to calculate PMF hydrograph ordinates.

Table 1: PMF Hydrograph Ordinates

TIME IN HR. (1)	ORDINATES OF U.H. IN (CUMEC) (2)	RAINFALL EXCESS IN (CMS) (3)	CRITICAL SEQUENCE OF RAINFALL EXCESS (4)	REARRANGED RAINFALL EXCESS (CMS) (5)	PMF HYDROGRAPH (CUMEC) (6)
0.00	0.00	0.00	3.20	0.11	25.50
0.50	0.69	3.20	0.78	0.11	25.57
1.00	2.92	3.20	0.78	0.11	25.88
1.50	6.25	1.45	0.78	0.11	26.55
2.00	9.73	1.45	0.78	0.11	27.58
2.50	12.82	1.20	1.20	0.11	28.94
3.00	15.28	1.20	1.20	0.11	30.57
3.50	17.01	1.20	1.20	0.11	32.37
4.00	18.05	1.20	1.45	0.11	34.29
4.50	59.11	1.20	3.20	0.11	40.57
5.00	18.37	1.20	3.20	0.11	42.53
5.50	17.87	0.78	1.45	0.11	44.42
6.00	17.06	0.78	1.20	0.11	46.24
6.50	16.04	0.78	1.20	0.11	47.94
7.00	14.88	0.78	1.20	0.11	49.52
7.50	0.00	0.78	0.78	0.11	49.52
8.00	0.00	0.78	0.78	0.11	49.52
8.50	0.00	0.78	0.78	0.11	49.52
9.00	0.00	0.78	0.78	0.11	49.52
9.50	0.00	0.78	0.78	0.11	49.52
10.00	0.00	0.78	0.78	0.11	49.52
10.50	0.00	0.78	0.78	0.11	49.52
11.00	0.00	0.78	0.51	0.11	49.52
11.50	0.00	0.51	0.51	0.25	49.52
12.00	0.00	0.51	0.51	0.25	49.62
12.50	0.00	0.51	0.51	0.25	50.05
13.00	0.00	0.51	0.51	0.25	50.96
13.50	0.00	0.51	0.51	0.25	52.38

14.00	0.00	0.51	0.51	0.25	52.25
14.50	0.00	0.51	0.51	0.25	56.48
15.00	0.00	0.51	0.51	0.25	58.96
15.50	0.00	0.51	0.51	0.25	61.59
16.00	0.00	0.51	0.51	0.25	70.21
16.50	0.00	0.51	0.51	0.25	72.89
17.00	0.00	0.51	0.39	0.25	75.5
17.50	0.00	0.39	0.39	0.25	77.98
18.00	0.00	0.39	0.39	0.25	80.32
18.50	0.00	0.39	0.39	0.25	82.49
19.00	0.00	0.39	0.39	0.25	82.49
19.50	0.00	0.39	0.39	0.25	82.49
20.00	0.00	0.39	0.39	0.25	82.49
20.50	0.00	0.39	0.39	0.25	82.49
21.00	0.00	0.39	0.39	0.25	82.49
21.50	0.00	0.39	0.39	0.25	82.49
22.00	0.00	0.39	0.39	0.25	82.49
22.50	0.00	0.39	0.39	0.25	82.49
23.00	0.00	0.39	0.25	0.25	82.49
23.50	0.00	0.25	0.25	0.39	82.49
24.00	0.00	0.25	0.25	0.39	82.59
24.50	0.00	0.25	0.25	0.39	82.59
25.00	0.00	0.25	0.25	0.39	83.83
25.50	0.00	0.25	0.25	0.39	85.14
26.00	0.00	0.25	0.25	0.39	86.68
26.50	0.00	0.25	0.25	0.39	88.95
27.00	0.00	0.25	0.25	0.39	91.25
27.50	0.00	0.25	0.25	0.39	93.70
28.00	0.00	0.25	0.25	0.39	101.70
28.5	0.00	0.25	0.25	0.39	104.19
29.00	0.00	0.25	0.25	0.51	106.61
29.50	0.00	0.25	0.25	0.51	108.92
30.00	0.00	0.25	0.25	0.51	111.18
30.50	0.00	0.25	0.25	0.51	113.56
31.00	0.00	0.25	0.25	0.51	114.34
31.50	0.00	0.25	0.25	0.51	115.56
32.00	0.00	0.25	0.25	0.51	117.16
32.50	0.00	0.25	0.25	0.51	119.07
33.00	0.00	0.25	0.25	0.51	121.19
33.50	0.00	0.25	0.25	0.51	123.45
34.00	0.00	0.25	0.25	0.51	130.84
34.50	0.00	0.25	0.25	0.51	133.14
35.00	0.00	0.25	0.11	0.51	135.37
35.50	0.00	0.11	0.11	0.78	137.50
36.00	0.00	0.11	0.11	0.78	139.69
36.50	0.00	0.11	0.11	0.78	142.35
37.00	0.00	0.11	0.11	0.78	144.04
37.50	0.00	0.11	0.11	0.78	146.67
38.00	0.00	0.11	0.11	0.78	150.15
38.50	0.00	0.11	0.11	0.78	154.28
39.00	0.00	0.11	0.11	1.20	158.89

39.50	0.00	0.11	0.11	1.20	164.07
40.00	0.00	0.11	0.11	1.20	181.3
40.50	0.00	0.11	0.11	1.45	188.88
41.00	0.00	0.11	0.11	3.20	197.94
41.50	0.00	0.11	0.11	3.20	209.84
42.00	0.00	0.11	0.11	1.45	227.23
42.50	0.00	0.11	0.11	1.20	250.50
43.00	0.00	0.11	0.11	1.20	272.97
43.50	0.00	0.11	0.11	1.20	312.18
44.00	0.00	0.11	0.11	0.78	332.24
44.50	0.00	0.11	0.11	0.78	348.82
45.00	0.00	0.11	0.11	0.78	371.14
45.50	0.00	0.11	0.11	0.78	449.61
46.00	0.00	0.11	0.11	3.20	452.59
46.50	0.00	0.11	0.00	0.00	376.49
47.00	0.00	0.00	0.00	0.00	361.91
47.50	0.00	0.00	0.00	0.00	356.49
48.00	0.00	0.00	0.00	0.00	344.19
48.50	0.00	0.00	0.00	0.00	287.09
49.00	0.00	0.00	0.00	0.00	245.28
49.50	0.00	0.00	0.00	0.00	226.35
50.00	0.00	0.00	0.00	0.00	208.42
50.50	0.00	0.00	0.00	0.00	286.83
51.00	0.00	0.00	0.00	0.00	135.87
51.50	0.00	0.00	0.00	0.00	120.26
52.00	0.00	0.00	0.00	0.00	104.30
52.50	0.00	0.00	0.00	0.00	88.47
53.00	0.00	0.00	0.00	0.00	73.11
53.50	0.00	0.00	0.00	0.00	25.50
54.00	0.00	0.00	0.00	0.00	25.50
54.50	0.00	0.00	0.00	0.00	25.50
55.00	0.00	0.00	0.00	0.00	25.50

The Graphical representation of results (table 1) is shown in Fig.1.

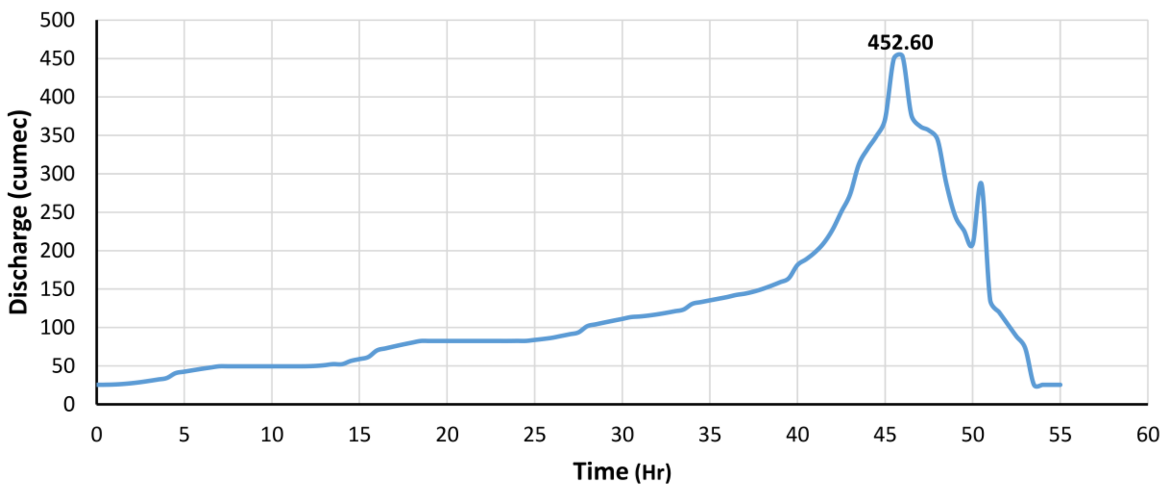

Figure 2: PMF Hydrograph.

To check the accuracy of present study methodology results are compared with results of CDO, Nasik. It is shown in table 2.

Table 2: PMF Peak

SR. NO.	STUDY CARRIED BY	PMF PEAK (CUMECS)
1	C.D.O. Nasik	1852.13
2	Present Study	452.60

The results of PMF peak are 1/3rd of the results obtained by CDO, Nasik. This variation may be due to non-availability of required data.

5. CONCLUSIONS

With this performed study, following conclusions can be made:

1) The PMP and PMF concepts have been with us for at least 50 years and perhaps longer. The PMF has been recognized as a standard of practice since about 1970.
2) If correlation of Nash model is used for deriving unit hydrograph, it does not give more acceptable results.
3) Instantaneous unit hydrograph (IUH) technique adopted is a unique demonstration of a particular catchment response to rain, independent of duration and is a graphical expression of the catchment parameters like length, shape, slope, etc., which control the response.
4) The construction of dams which are key hydraulic structures to any conservation projects, cannot be altogether dispensed with. For new projects more stringent control from point of dam safety will have to be exercised in the planning, investigations, and design, construction and operation stages.

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