

Estimation of Design Flood at Kol Dam using Hydrometeorological Approach



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Submission: June 28, 2017; Published: July 31, 2017

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Abstract

Reliable estimation of design flood is critically important for the design of water resources infrastructure. At sites where the stream flow data is not available for a sufficiently long period of time, frequency analysis cannot be carried out for the estimation of floods with different return periods. A methodology based on hydrometeorological approach has been presented for the estimation of design flood at Kol Dam - a major reservoir in the Satluj River Basin. In the absence of concurrent rainfall intensity and stream flow data at the Kol Dam site, Snyder's method was applied to develop synthetic unit hydrograph. The values of the standard project storm and probable maximum storm required for the computation of ordinates of 2-day probable maximum flood hydrograph, and 2-day standard project hydrograph at the Kol Dam site were based upon the recommendations of the Central Water Commission of India. The peak of the probable maximum flood hydrograph was found to be significantly higher than the peak of the standard project flood hydrograph. Therefore, it is recommended that the design flood at the Kol Dam site shall be based on the probable maximum flood hydrograph. The research methodology presented herein is easily transportable to other sites where the availability of rainfall and discharge is limited.

Keywords: Flood; Kol; Dam; Hydro-meteorological; Rainfall, Satluj

Abbreviations: LP3: Log-Pearson type III; CWC: Central Water Commission; RDSO: Research Designs and Standards Organization; SPF: Standard project flood; PMF: Probable maximum flood

Introduction

Floods are an important component of the geological history of our planet. Flooding occurs

- Along rivers, streams and lakes.
- In coastal areas, and
- On alluvial fans. Flooding can also occur in ground failure areas such as subsidence. Owing to large scale urbanization in cities, green spaces have shrunk considerably, giving way to paved surfaces. In many cases, this results in increased run off from land areas leading to urban flooding.

Incidences of urban flooding are on the rise due to the increase in the magnitude and frequency of extreme precipitation events as a manifestation of climate change. Locally inadequate drainage systems coupled with loss of green spaces have considerably increased the incidences of urban flooding in cities around the world. The problem of flooding is more severe in developing countries compared to the developed countries.

This is primarily due to the absence of strict guidelines for the use of floodplains, which is the dry land area adjoining rivers, streams, lakes, bays or oceans. Human settlements and activities have always tended to use floodplains. Floodplains are likely to be inundated even during moderate floods. During the floods of relatively higher magnitude, the inundation takes place in areas beyond the flood plains. The risk due to flooding, both in terms of economic losses and environmental losses is likely to be exacerbated under the impact the influence of climate change.

Flood management requires response of the agencies on various fronts. Both structural and non-structural measures are required for effective flood control. The objective of the structural approach is to control the effects of the hazard by using specific engineering works as the best means of protecting life and property. On the other hand, the objective of the non-structural approach is to modify susceptibility to flood hazard through a range of controls and other non-engineering devices. The reduction in flood-related deaths and damages can be directly

attributable to the efficiency with which these structural and non-structural measures are implemented. For implementation of the structural and non-structural measures, the hydrologic and hydraulic analysis of floods are required. These analyses are needed for determining potential flood elevations and depths, areas of inundation, sizing of channels, levee heights right of way limits, design of highway crossing and culverts, and many others.

The peak discharges of stream flow from rainfall can be obtained from the design storm by the hydrographs developed from the unit hydrographs generated using the established methods. Wilson [1] observed that with an adjustment and well measured rating curve the daily gauge readings may be converted directly to runoff volume. The author also emphasized that catchment properties influence runoff to a considerable extent. The catchment properties include area, slope, orientation, shape, altitude and also stream pattern in the basin. A vast amount of literature exists, treating the various unit hydrograph methods and their development. Jones [2] reported that was the first to explain the procedure for the development of the unit hydrograph method for watersheds of 5000 km² or less. Chow et al. [3] discussed the derivation of unit hydrograph based on linear systems theory. Ramirez [4] reported that the synthetic unit hydrograph of Snyder in [5] was based on the study of 20 watersheds located in the Appalachian Highlands and varying in size from 25 to 250000 km². Ramirez [4] reported that the dimensionless unit hydrograph was developed by the Soil Conservation Service and obtained from the UH's for a great number of watersheds of different sizes.

Vijay et al. [6] describes a hydrodynamic model called River CAD that provides the flood levels and land availability at various cross-sections in order to assess the inundation and evaluate the possibilities for riverbed development. Timbadiya [7] describes a study aimed at determining values of Manning's roughness coefficients for upper and lower reaches of the lower Tapi River for simulation of flood. Khattak et al. [8] describe the application of HECRAS model to the development of floodplain maps for the part of Kabul river that lies in Pakistan. Conventional flood frequency analysis, involving log-normal, Gumbel's, and log-Pearson type III (LP3) distributions, was used to calculate extreme flows with different return periods. Sankhua et al. [9] focused on the concepts of hydraulic flood routing model, with time-varying roughness updating to simulate flows through natural channels, based on the quasi-steady dynamic wave and full dynamic wave theory, emphasizing the solving of the intricate Saint Venant's equation.

Several recommendations have been made by the Central Water Commission (CWC), Research Designs and Standards Organization (RDSO), and India Meteorological Department using the method based on synthetic unit hydrograph and design rainfall, considering physiographic and meteorological characteristics for estimation of design floods CWC [10]. The

regional flood frequency studies carried out by RDSO using the pooled curve methods RDSO [11] for various hydro-meteorological subzones of India. Reliable estimation of design floods is the most important component of hydraulic design. Choosing a value much higher than the anticipated value of design flood under a given return period would lead to the uneconomical design of the system. A value of the design flood on the lower side of the anticipated value under a given return period would increase the risk of failure of the system. The consequences of inadequate safety in the design of water resource systems could lead to devastating impact on the life and property of the inhabitants. Two common approaches for the estimation of design flood are either adopting the standard project flood (SPF) or the probable maximum flood (PMF).

The SPF is the flood that would result from a severe combination of meteorological and hydrological factors reasonably applicable to the region. Extremely rare combinations of factors are excluded in computing the SPF. The PMF is the extreme flood that is physically possible in a region as a result of most severe combinations including rare combinations of meteorological and hydrological factors. The PMF is used in situations where a failure of the structure would result in loss of life and catastrophic damage and as such complete security from potential floods is sought. Estimation of flood hazard can be carried out using methods of varying complexity depending on data, resources, and time availability Ouma and Tateishi [12]. The four basic approaches for the estimation of flood include,

- I. Frequency analysis
- II. Use of empirical formulae,
- III. Unit hydrograph method, and
- IV. Hydro-meteorological approach. The objective of the present paper is to compute the magnitude of design flood at Kol Dam using the hydro-meteorological approach.

Study Area

The Satluj River is a major river of the Indus system, which originates from Mansarowar Lake in Tibet. The catchment of the river up to the Bhakra Dam site lies between North latitudes 30° and 33° and east longitudes 76° and 83°. It enters India near Shipkila at an elevation of about 2530 meters and continues to flow in Himachal Pradesh through Wang too and Kina before reaching Bhakra Dam. The principal tributaries of the Satluj are the Spiti Kashming, Baspa, Bhabha, Nogli, Korpan, Nauti, Sholding, Seer, Bharari, Ali and Ghamber khad.

The elevation of the bed is about 4570 meters near Lake Mansarowar, 2530 meters near Shipkila, 915 meters near Rampur, 460 meters near Bilaspur and 350 meters near the Bhakra Dam site. The bed slope of the river is flat from Shipkila to Jangli dam site for a distance of about 42 km, which is of the order of 1 in 175. It becomes steep between Jangli Dam site and

Rampur, the slope being 1 in 87 and is again flat from Rampur to Kol Dam site with a slope of 1 in 300. The slope is flattest in the Bhakra reservoir area, the portion downstream of the Kol Dam, where the bed slope is 1 in 500. A gross fall of 2180 meters is available in the river bed from Shipkila to Bhakra in a length of about 320 Km. The valley is narrow in the portion from Shipkila to Pooh and from Thopan to Rampur. In the segment between Pooh to Toppan and between Rampur to Bhakra the valley is comparatively wide. The valley is widest in the segment immediately upstream of Bhakra.

Kol Dam Hydroelectric Project

The 800 MW Kol Dam hydro electric projects in Himachal Pradesh was constructed by National Thermal Power Corporation at an estimated cost of Rs 5300 core in district Bilaspur of Himachal Pradesh, India. A 163 m high rock fill dam has been constructed across River Satluj 6 km upstream from the existing Dehar power station. The power station has four turbine units of 200 MW each. The power generated is being supplied to power deficient northern region through 400 KV integrated transmission system lines constructed for Nathpa Jhakri and Kol dam projects [13].

Methodology

The unit hydrograph can be developed for a specific catchment provided that the discharge data is available for at least five years. The flood peak is then obtained by applying appropriate storm values to the unit hydrograph ordinates. In the absence of site specific discharge which is generally the situation in case of small and medium catchments the other approach open to the hydrologist is to evolve a regional frequency storm rainfall-synthetic unit hydrograph model for a hydro- meteorologically homogeneous region. This involves the collection of requisite concurrent rainfall and runoff data of small and medium representative catchments numbering 15 to 20 in a region over a period of 5 to 6 years for a systematic analysis of storm rainfall and flood events to derive representative unit hydrograph (RUG). These RUG's reflect the hydrologic behaviour of catchments with their own physiographic characteristics.

Regional relationships are established between the physiographic and RUG parameters to derive a synthetic unit hydrograph for engaged small and medium catchments in the same region. Besides, frequency point rainfall maps for different return periods and duration are prepared for a region on the basis of available long term daily or short duration data of reengages networks. Areal and time distribution factors are also evolved for time increments equal to the unit duration of synthetic unit hydrograph (SUH) from design storm duration. Model value of the constant loss rate based on analysis of selected storm rainfall and flood event is estimated for conversion of design storm rainfall units to effective rainfall. The effective rainfall is then applied in a critical sequence to SUH for obtaining the direct

runoff hydrograph. The base flow is added to the total direct runoff to obtain the total flow corresponding to frequency storm rainfall.

The following physiographic parameters have been used to determine the SUH.

Physiographic parameters

- a. Identify the boundary of catchment by using the appropriate topography sheet and determine the catchment areas (A).
- b. Measure the length of the longest stream in km (L).
- c. Determine the length of the stream from a point opposite to centre of gravity of the catchment to the point of study in km (L_c).
- d. Compute equivalent slope in m/km (S).

Results and Discussion

The absence of concurrent rainfall intensity data and hourly flow records require that the unit hydrograph be developed by some means other than the adjustment of an observed hydrograph. Synthetic unit hydrograph are derived based on Snyder's method. The lag time, t_p from the centroid of unit rainfall excess to the peak of the unit hydrograph is given by

$$t_p = C_t (LL_c)^{0.3}$$

$$t_r = t_p / 5.5$$

$$t_p' = t_p + 0.25(t_r - t_p)$$

$$Q_p = (C_p A) / (t_p')$$

$$T_p = (t_p + 0.5t_r)$$

$$T_B = 2.67T_p$$

Where t_r = desired unit-hydrograph duration (hour)

t_p = Duration of the unit rainfall excess (hour)

t_p^{\wedge} = adjusted lag time (hour)

TB = time base of unit hydrograph (hour)

Q_p = peak discharge (m^3/sec)

A = effective catchment area (km^2)

L = river length from dam to upstream limit of effective catchment (km)

L_c = river length from dam to a point on the river nearest to the centre of gravity of effective drainage area (km)

C_t = a regional constant representing watershed slope and storage. The value of $[C_t]$ in Snyder's method ranged from 1 to 2.2

C_p = a coefficient ranging from 4 to 5 for Snyder's method

The India Meteorological Department recommended an effective catchment area of 6,700 km² to the Bhakra Beas Management Board for their studies on storm events for Bhakra Dam. The effective catchment area is the area over which the storm rainfall may be considered to occur. Subtracting the 3,105 km² of drainage area between the Kol Dam site and Bhakra Dam, it leaves an effective catchment area of 3595 km² upstream of proposed Kol Dam site. The values of L , L_c and S corresponding to the effective catchment are worked out as

$$L = 136 \text{ km}$$

$$L_c = 73 \text{ km}$$

$$S = 3.412 \text{ m/km}$$

As the basin has steep slopes (the equivalent slope in the effective catchment is 3.412 m/km) a value of C_t of 1.2 was adopted. Similarly, an average value of C_p was chosen as 4.5. These values are substituted into Snyder's equations to estimate the following parameters of the SUH (Figure 1).

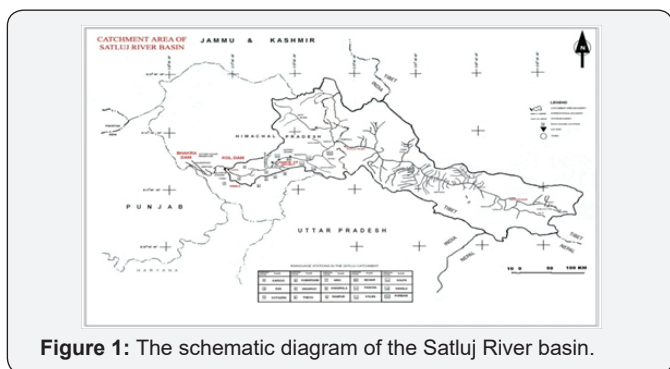


Figure 1: The schematic diagram of the Satluj River basin.

$$Q_p = 851.44 \text{ m}^3/\text{s}$$

$$t_p = 18.97 \text{ hours}$$

$$t_r = t_p/5.5 = 3.44 \text{ hours (say, 3 hours)}$$

$$t_p' = t_p + 0.25(t_r - t_p) = 18.86 = 19 \text{ hours}$$

$$[T]_p = (t_p + 0.5t_r) = 20.5, \text{ say } 21 \text{ hrs}$$

$$T_B = 2.67T_p = 56.07 \text{ hours (say 57 hours)}$$

Table 1: The salient features of Koldam Hydroelectric Power Project .

Name of the project	Koldam Hydroelectric Power Project
Location	On river Satluj in Bilaspur Distt.(H.P.) 6 Kms upstream of Dehar Project of Bhakra Beas management Board
Geographical coordinates	31°22'59"N 76°52'16"E
Dam and Spillway	
Type of dam	Embankment, rock-fill with clay core

Height (foundation)	167 m
Height (thalweg)	153 m
Length	474 m
Elevation at crest	648 m
Width of crest	14 m
Dam volume	12,000,000 m ³
Spillway type	Chute, six radial gates
Spillway capacity	16,500 m ³ /s
Reservoir	
Maximum Reservoir Level EL	646 m
Full Reservoir Level EL	642 m
Minimum Draw down Level EL	636 m
Total capacity	560,000,000 m ³
Maximum length	40 km
Normal elevation	642 m
Power station	
Hydraulic head	144 m (static)
Turbines	4 x 200 MW Francis-type
Installed Capacity	800 MW

Table 2: 3-hour synthetic unit hydrograph ordinate at the Kol Dam site

Time(hr)	UG Ordinate (m ³ /s)	Time (hr)	UG Ordinate (m ³ /s)
0	0.00	30	265.00
3	2.00	33	175.00
6	10.00	36	115.00
9	35.00	39	80.00
12	95.00	42	50.00
15	185.00	45	30.00
18	400.00	48	15.00
21	851.44	51	6.00
24	625.00	54	2.00
27	400.00	57	0.00

Considering the steep slope of the river, T_B has been considered as $2.67 T_p$. Based on the above parameters, a 3 - hour SUH has been developed after adjusting the volume to 1 cm and is shown in Figure 2. The ordinates of the synthetic unit hydrograph are provided in Tables 1 & 2. Design Storm

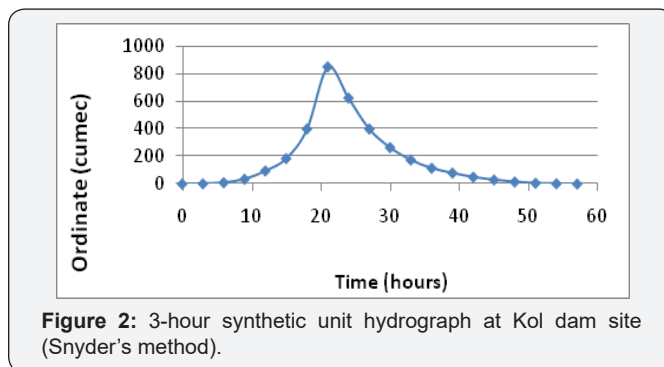


Figure 2: 3-hour synthetic unit hydrograph at Kol dam site (Snyder's method).

Data on storm rainfall as provided by the Bhakra Beas Management Board (BBMB) for use at Bhakra Dam was considered appropriate for Kol Dam since Kol dam site is around 70 km upstream on the same river. The values of standard project storm (SPS) and probable maximum storm (PMS) are provided in Table 3 CWC [14]. The distribution of 24-hour and 48-hour storm rainfall is provided in Table 3 and Table 4, respectively. The report of the CWC [14,15], recommends $T_D=1.1t_p$ or $T_D=T_B$. Using these values, the duration of the storm has been worked out as 23 hours and 57 hours respectively. It was decided to adopt $T_D= 48$ hours (for Snyder’s method) to obtain 2-day PMF hydrograph. The incremental rainfall excess values of each bell are calculated based on the temporal distribution given by India Meteorological Department (IMD) and each bell is arranged in order of unit hydrograph ordinates and reversed. Each bell is placed critically so that the sum of the two bells does not exceed the 24 hour PMS value.

Table 3: Standard project storm (SPS) and probable maximum storm rainfall (PMS).

Duration (h)	SPS (mm)	PMS (mm)
24	224	325
48	338	490
72	452	655

Table 4: Distribution of 24-h storm rainfall

Time	24 Hour Event	
	Cumulative %	Incremental %
0	0	-
3	50	50
6	67	17
9	78	11
12	86	8
15	92	6
18	96	4
21	99	3
24	100	1

Loss Rate and Base Flow

A loss rate of 5 mm/h has been adopted as recommended in the flood estimation report of CWC [14]. Since the major part of the catchment is snow bound, it is evident that the base flow is mainly generated from the snow melt phenomenon. Therefore, a tentative estimate of base flow, including snow melts component during the month of June when the snow melts rate is expected to be maximum has been carried out. From the analysis of monthly mean rainfall and runoff were for the month of June over the period 1967 to 1996, the mean rainfall and runoff were found to be 93 mm and 604 mm, respectively. Considering a runoff factor of 0.50, the runoff contributed by rainfall has been deducted from total runoff to segregate the average snow melt runoff to be considered as base flow which is worked out as 773

cumec. A base flow of 800 cumec has been adopted in this study (Tables 4 & 5).

Table 5: Distribution of 48-h storm rainfall.

Time (h)	48 Hour Event	
	Cumulative %	Incremental %
0	0	-
3	28	28
6	39	11
9	47	8
12	55	8
15	61	6
18	67	6
21	72	5
24	77	5
27	82	5
30	87	5
33	91	4
36	94	3
39	96	2
42	98	2
45	99	1
48	100	1

The 3-hour rainfall excess values of 2-day PMS and 2-day SPS value of 490 mm 338 mm, respectively arranged in critical sequence are convoluted with UG ordinates to obtain the PMF hydrograph and SPF hydrograph. The peak of the PMF hydrograph and peak of SPF hydrograph is worked out as 15705 m³/s and 9998 m³/s respectively. The design PMF hydrograph and SPF hydrographs are presented in Figure 3 and Figure 4, respectively (Figure 3).

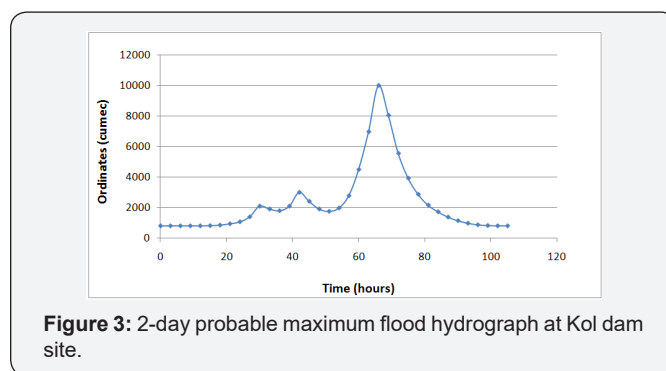


Figure 3: 2-day probable maximum flood hydrograph at Kol dam site.

Conclusion

The research presented herein describes the computation of SPF and PMF for a dam site with limited discharge data availability. At sites where the rainfall or design records are not available for an adequate length of time, it is difficult for the hydrologists to arrive at reasonably accurate estimates of design flood. An alternative approach to overcome this problem

is to utilize the hydro-meteorological data from hydrologically homogeneous catchments in the vicinity of the site of interest. For several regions in India, even this approach becomes impractical due to the absence of required data for the neighboring sites. Another approach that is often utilized by the engineers is to apply empirical formulae for the estimation of design flood. The limitation associated with the empirical formulae is that they are region-specific, and therefore provide reliable results only for the regions they have been developed for. Additionally, most empirical formulae do not consider the return period while estimating the design flood. Therefore, it is a challenging task to estimate design flood for the design of hydraulic structures at sites where the data availability is poor (Figure 4).

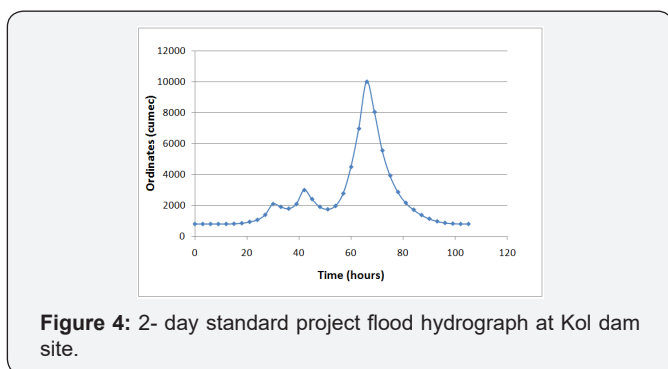


Figure 4: 2- day standard project flood hydrograph at Kol dam site.

The methodology presented in the present research aims to address this issue, and is particularly useful for the computation of design flood at un-gauged sites or sites with limited discharge data. In the absence of observed hydrograph on the Kol dam site, the unit hydrograph was developed using the Snyder's method - a widely accepted method for the development of the synthetic unit hydrograph. Based upon the recommendations of the CWC, the values of SPS and PMS were utilized for the computation of ordinates of 2-day probable maximum flood hydrograph, and 2-day standard project hydrograph at the Kol Dam site. Clearly, the type and importance of the hydraulic structure dictate the design criteria for selecting the flood magnitude. However, in the absence of reliable rainfall and discharge data, it is recommended that the design flood at Kol Dam be based on the peak of the PMF hydrograph as the peak of the PMF hydrograph is significantly higher than the peak of SPF hydrograph. It can be concluded that

the hydro-meteorological approach presented herein is easily transportable to other sites with limited or zero data availability with minimal changes.

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DOI: 10.19080/IJESNR.2017.04.555627

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