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Increasing Storage by Raising WALA Dam in Jordan

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Abstract

WALA dam in Jordan was constructed in November 2002 with storage capacity of 9.3 MCM. The present study investigates and supports the importance of increasig the storage capacity of an existing dam in Jordan. This needs raising RCC stepped spillway and the embankment parts of the existing dam. Using measured data from water balance of the dam reservoir, different hydrological techniques are applied to assess the reservoir storage capacity and the necessary raising of dam height. Results show that RCC spillway can be raised by 15.4, 16.7, 18, and 19.9 m for design periods 30, 50, 70, and 100 year respectively, and the storage capacity will be increased from the existing 9.3 MCM to 30.5, 32.4, 34.3, or 37.2 MCM. Flood frequency and flood routing are conducted to determine the maximum flood level in the reservoir and for different return periods. For return period 10^4 year the embankment parts of the dam need raising 16.6, 17.9, 19.2, or 21.1 m for design periods 30, 50, 70, and 100 year, respectively.

Keywords: Raising Dams, RCC Spillway, Embankments, WALA Dam, Storage Capacity, Jordan.

INTRODUCTION

There is no doubt that the issue of water in Jordan, which tops the list of the poorest countries in water, is the first priority of national policy makers in an attempt to reach real solutions. Jordan is classified as being a semi-arid to arid region with annual rainfall of lea than 200 mm over 80% of the land. The Ministry of Water and Irrigation in Jordan has taken pioneering steps towards integrated water sector planning through a national strategic plan to ensure that the necessary water needs are met, such as projects aimed at increasing the storage capacity of dams. The implementation of the WALA dam raising project aimed at increasing the existing dam storage capacity. For WALA catchment area, several relevant studies (Hadadin (2016), Ijam an Tarawneh (2012), Al-Balawi (2003), Zaarir (1995), Hadadin (1992), Ismail (1986)) have been carried out to study the stream flow analysis, sedimentation yield, dam reservoir capacity, rainfall-runoff relationship and components of the surface water. Up to the researcher knowledge, there is no published research on raising dams in Jordan. The following review is published research on raising dams outside Jordan.

Bischoff and Obermeyer (1993) presented a general discussion of the factors to be considered in designing raises to existing dams for increased storage. Nillson and Ekstrom (2004) investigated the problems of stability and raise the Swedish Ajaure embankment dam by 5 m. Pagues (2010) assessed the feasibility of and addressed concerns with a crest raise for Rattlesnake Hollow Ash pond dam located in Alabama, U.S.A. The dam underwent a major renovation in 1979, with a crest raise of 17 m. A second crest raise was evaluated and a decision was made to raise the existing dam 6 m, bringing the total height to 50 m. Bakheet (2012) studied Umdafog dam in Sudan, and found its existing storage is only 13% the annual yield. The dam can be raised by 3 m without severely affecting the downstream users. This additional height will increase the storage capacity to about 46 MCM, which can satisfy the demand for water in the region. The current study search for how much the existing WALA dam height can be raised to increase its storage capacity using measured data on water balance of its reservoir.

WALA DAM FEATURES

WALA watershed is located at the top of the MUJIB basin, covering a triangular shaped region of nearly 2000 km^2. The area encompasses several intermittent Wads draining westerly from the highlands in the east, northeast, and north to the lowlands of Jordan Valley. The confluence of these Wads forms Wad WALA, being one of the two major tributaries of the MUJIB stream system, the other is Wad MUJIB that drains MUJIB watershed. The present use of water resources in Wad WALA area depends mainly on surface water resources and groundwater wells. The topography of the area varies in altitude from a minimum height about 500 m above mean sea level (a.msl) in the southwest, to a maximum about 950 m a.msl to the east of Madaba.

WALA dam function is to facilitate groundwater recharge to the underlying aquifers, which are being used for drinking water supply to Amman through HEIDAN well field. The storage capacity is 9.3 MCM at full reservoir level 520 m a.msl. The total dam length is 380 m, consists of 105 m RCC stepped spillway with crest level 520 m a.msl and 137.5 m earth-fill embankment on each side of the spillway with crest level 524 m a.msl. Since November 2002, the dam has been flooded when the reservoir level is higher than 520 m a.msl. The general dam sections before and after raising construction can be visualized as shown in Figure (1).

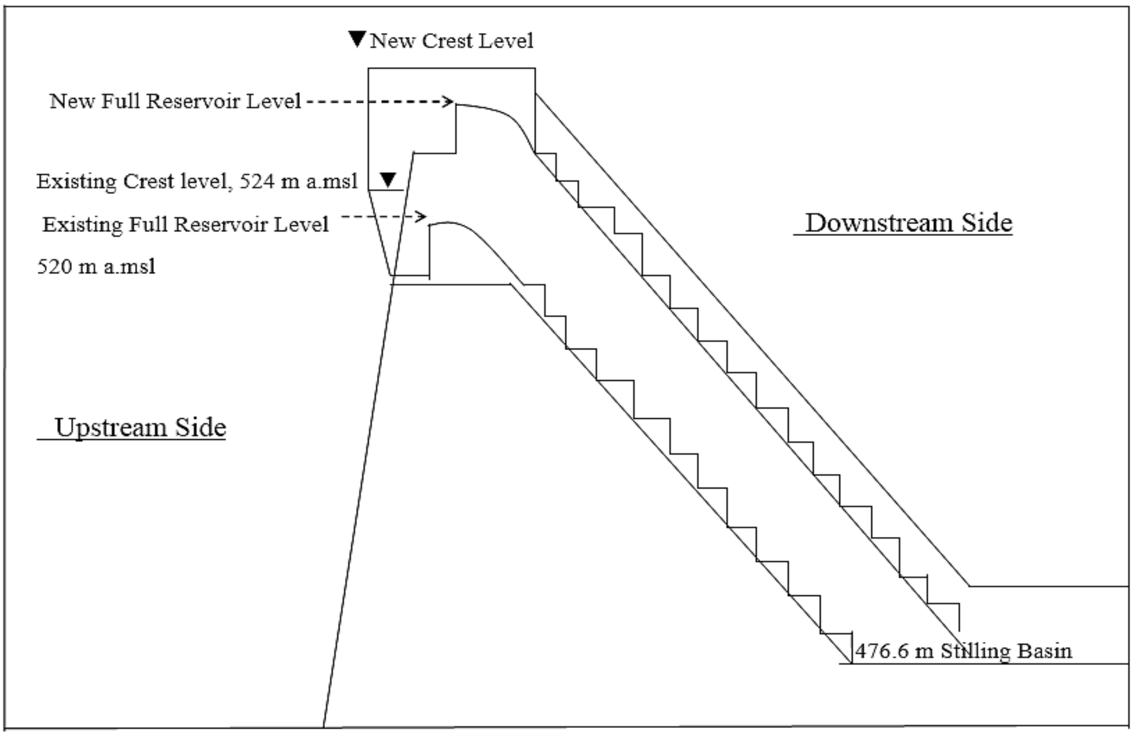

Figure (1) General Sections for Raising WALA Dam

Availability of Data

Data has been collected from the Ministry of Water and Irrigation in Jordan and the Jordan Valley Authority/ Dams Directorate. Daily measurements of reservoir water level, reservoir water volume, inflow, and outflow quantities for the period November 2002 to December 2017 are put in monthly time series as listed by AlSaraireh (2018). The annual inflow and outflow from WALA reservoir are shown in Figure (2). The outflow shown does not include spilled water.

WALA dam reservoir contour map as given by the Consultant Howard and Humphreys (1992) is used to get the following relationships by regression:

$H = -4.603 A^4 + 29.82 A^3 - 69\ 36 A^2 + 82.81 A$ .... (1)

$V = 13.3 A^{1.364}$ ....(2)

Where,

H = water surface elevation above the upstream bed level of the dam, it equals 484.9 m a.msl,

A = reservoir water surface area in km^2,

V = reservoir storage volume in MCM.

These relationships are used to determine the full reservoir level for the determined storage capacity.

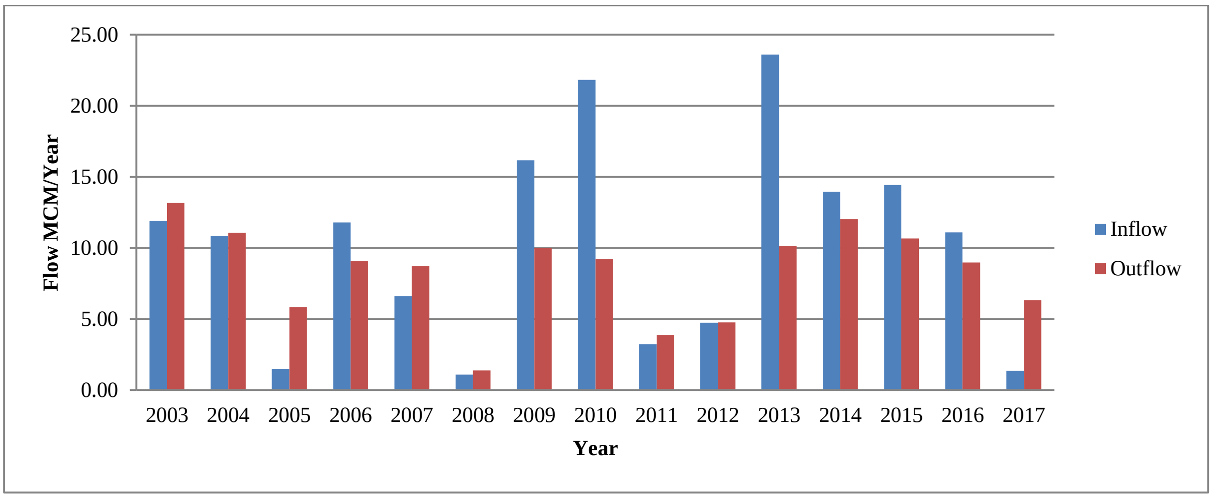

Figure (2) The Inflow and Outflow of WALA Dam Reservoir

METHODOLOGY

Estimation of Reservoir Storage Capacity:

The sequent peaks method (Mays, 2010) is used to determine the possible reservoir storage capacity. This method is more suitable and commonly used when lengthy data are to be analyzed as the case in this work. In this method compute the cumulative sum of inflow QF_t minus the reservoir releases R_t (including evaporation and seepage), the following equation is used;

$$\sum_t U_t = \sum_t (QF_t - R_t) \qquad \ldots\ldots\ldots\ldots(3)$$

where U_t is the inflow minus reservoir releases. From plotting U_t with time, the required storage is the vertical difference between the first peak and the low point before the sequent peak as shown in Figure (3).

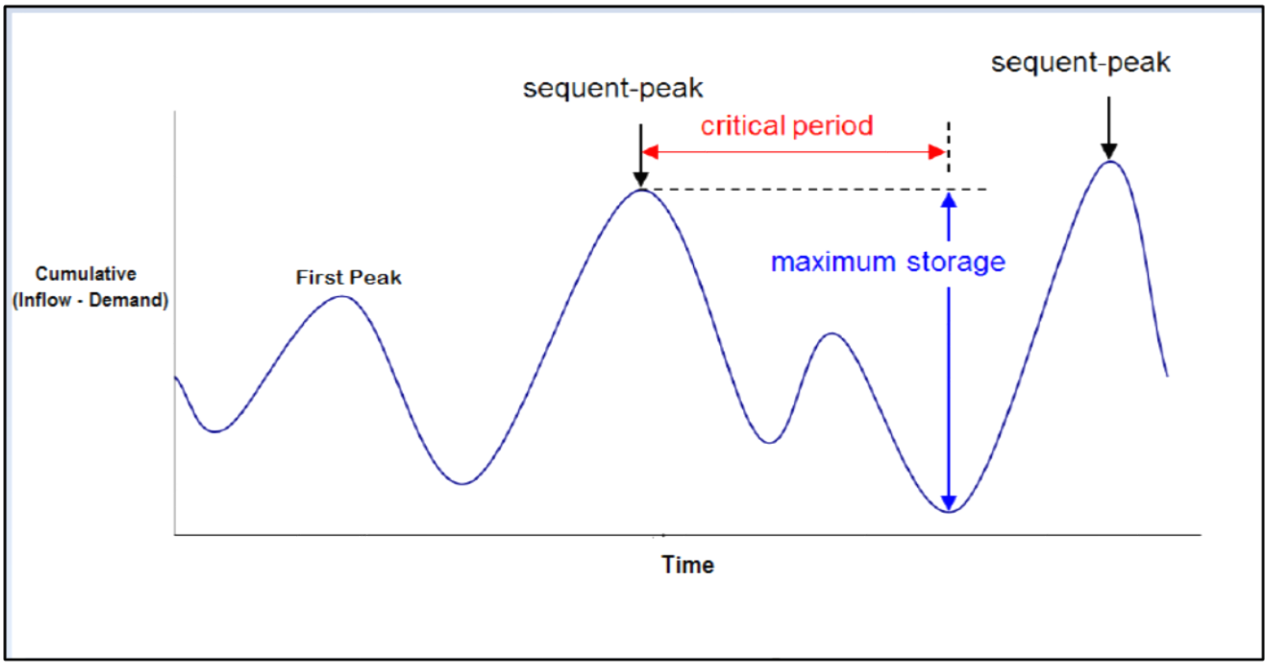

Figure (3) Sequent Peaks Method Terminology

Flood Frequency Analysis:

The objective of frequency analysis of hydrological data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution. It is recommended by many researchers to use Log-Pearson Type III distribution as a base distribution for flood frequency studies. The details of this method introduced by Chow, (1988), and will be employed for WALA dam reservoir. In this analysis, the annual maximum discharge is selected as the largest instantaneous peak flow occurring at any time during the year with the expectation that successive observations of this variable from year to year will be independent. To determine the peak flow rate due to daily runoff, the equation derived by Neitsch et al. (2005) is appropriate to be used for WALA catchment:

$$Q_{peak} = \frac{1}{3.6} \text{ x } \frac{Q}{Tc} \text{ x } A \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where; Q_{peak} is peak runoff rate (m^3/ sec), Q is the daily measured runoff reaches the dam reservoir in mm, T_c is the catchment time of concentration in hours, and A is the catchment area in km^2.

The time of concentration depends on the geometric parameters of the catchment. The U.S.B.R (1987) equation for T_c is;

$$T_C = 0.948\left(\frac{L^3}{\Delta H}\right)^{0.385} \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

Where, T_c is time of concentration in hours, L is the length of the longest drainage channel in Km, and ΔH is the difference in elevation between the start of the drainage channel and the elevation at the dam site in m.

For WALA catchment, A = 1770 km^2, L = 90 km, ΔH = 380 m, and T_c = 17.4 hr.

The annual maximum discharge is selected from the application of equation (4) for the measured daily values of Q in mm.

Reservoir Flood Routing:

Flood routing is the process of computing the water levels in the reservoir and the outflow rates corresponding to a particular inflow hydrograph at various instants of time. It is essential to determine the maximum flood reservoir level and the corresponding outflow rate when the maximum flood passes over the spillway. Standard reservoir flood routing is followed as given bt Mays (2010).

Since there is no measured inflow hydrograph for WALA catchment, a triangular shaped hydrograph is assumed. The peak of the hydrograph equals the maximum flood flow rate determined from frequency analysis. The time to peak is calculated from the equation (Viessman and Lewis, 2003);

$$T_P = \frac{T_r}{2} + (0.6 \times T_c) \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Where,

T_P: time to peak flow in hours.

T_r : design storm duration in hours, a value of 6 hours is used, therefore T_p = 13.44 hr.

The base of the inflow hydrograph is taken as a multiple of the time to peak :

$$T_b = 2.67x\ T_p \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Therefore T_b = 35.9 hr.

The relationships for WALA reservoir equations (1) and (2) are used with the free flow discharge equation over spillways:

$$Q_{outflow} = C_d . \sqrt{2g} . L \ . H_w{}^{3/2} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Where,

$Q_{outflow}$ = Outflow discharge (m^3/sec).

C_d = the dimensionless coefficient of discharge, equals 0.492, (USBR, 1987).

L = the crest length of the spillway (L = 105 m for WALA dam).

H_w = The total head of water above the crest level of the spillway.

RESULTS AND DISCUSSIONS

Reservoir Storage Capacity:

The monthly values of inflow for the period November 2002 to December 2017 are used to conduct sequent peaks analysis to estimate the reservoir storage capacity. One of the objectives is to make use of all available water in future without spilled water over the spillway. Therefore, a uniform yield can be assumed and equals the total cumulative inflow during the critical period (182 month) divided by 182 month, it equals 0.9 MCM/ month including evaporation and seepage. It is noticed the critical sequence of flows occurred at the end of the inflow record, in this case the period of analysis is doubled from 182 month to 364 month with inflow sequence repeating itself in the second period and the analysis proceeds. The results of sequent peaks analysis are plotted in Figure (4), the analysis gives 27.69 MCM of water the reservoir capacity.

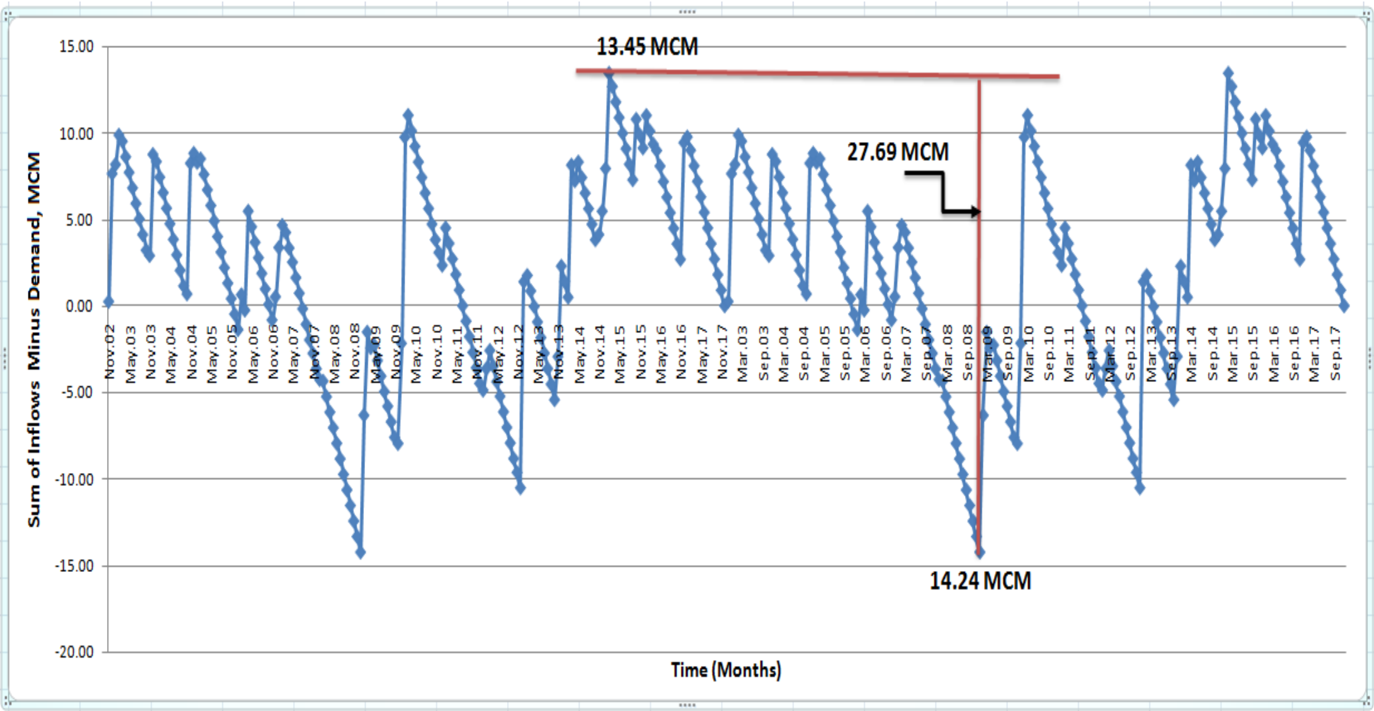

Figure (4) Sequent Peak Analysis for WALA Dam Reservoir

The storage capacity obtained from sequent peak analysis is modified by adding the expected volume of sedimentation in the reservoir 0.0947 MCM/ year as predicted by Ijam and Tarawneh (2012). For different design periods, the storage capacity including sedimentation are obtained to be substituted in equations (1) and (2) to determine the full reservoir level and dam raising as shown in table (1). Data shown in table (1) based on existing spillway crest level equals 520 m a.msl. The raising height ranges from 15.4 m to 19.9 m for design period 30 year to 100 year, respectively.

Table (1)

Design Period Year	Storage Capacity MCM	Full Reservoir Level m, amsl	Dam Raising m
30	30.5	535.4	15.4
50	32.4	536.7	16.7
70	34.3	538.0	18.0
100	37.2	539.9	19.9

Flood Frequency Analysis:

The annual maximum discharge is selected from the application of equation (4) for the maximum measured daily values of Q in mm, using T_c = 17.4 hr and A = 1770 km^2. Results are shown in table (2).

Table (2)

Annual Peak Discharge in m^3/ sec at WALA Dam Site.

Year	Max. Daily Inflow, MCM	Max. Daily Runoff, mm	Peak Flow Rate, Q m^3/ sec
2002/2003	3.53	1.99	56.28
2003/2004	6.07	3.43	96.93
2004/2005	8.01	4.53	127.93
2005/2006	6.34	3.58	101.17
2006/2007	2.12	1.20	33.91
2007/2008	0.58	0.33	9.21
2008/2009	4.41	2.49	70.47
2009/2010	6.78	3.83	108.17
2010/2011	0.89	0.50	14.18
2011/2012	1.24	0.70	19.82
2012/2013	6.06	3.42	96.69
2013/2014	3.05	1.72	48.64
2014/2015	3.92	2.22	62.66
2015/2016	3.69	2.08	58.84
2016/2017	6.43	3.63	102.66

The Log-Pearson type III distribution is applied using the results shown in table (2) for different return periods. The Log-Pearson type III frequency curve for peak annual flows into WALA dam reservoir are plotted in Figure (5). It is clear from figure (5) the relation is not linear. It is worth to mention the existing WALA dam was designed for return period 10^4 year (for probability 10^{-4}) by the consultant Howard and Humphreys (1992).

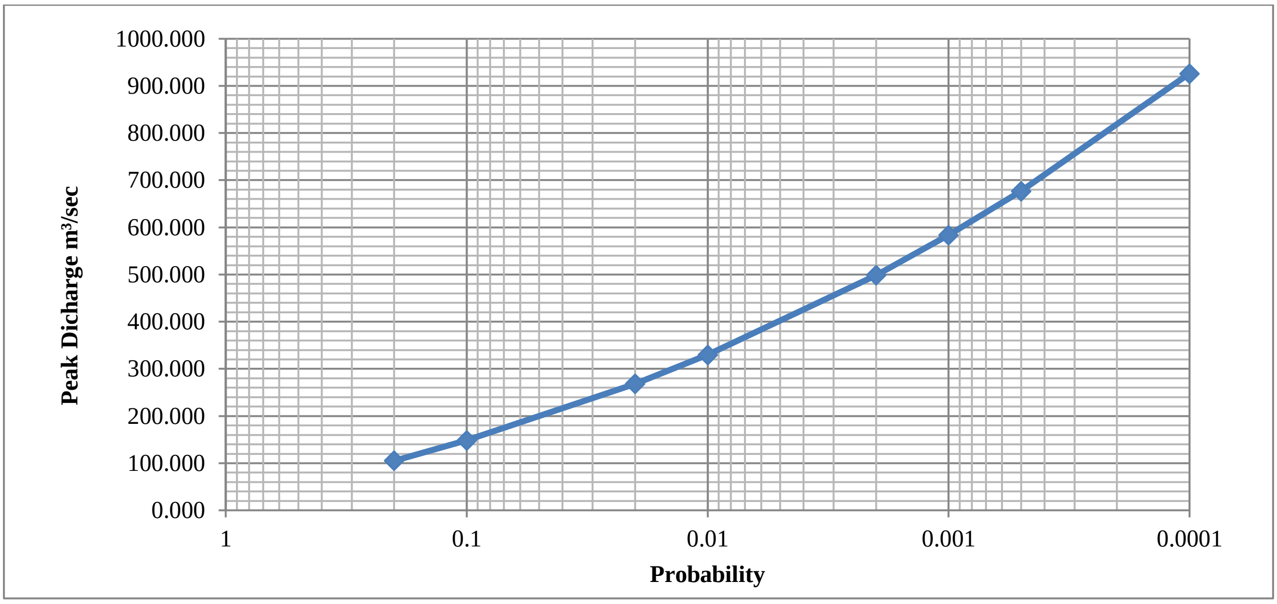

Figure (5) The Log-Pearson type III Frequency Curve for Peak Annual Flows

Reservoir Flood Routing:

Flood routing is carried out to determine the maximum flood reservoir level and maximum flood flow over the spillway. The maximum flood reservoir level plus allowable freeboard gives the total crest height of the dam. Since there is no measured inflow hydrograph for WALA catchment, a triangular shaped hydrograph is assumed. The peak of the hydrograph equals the maximum flood flow rate determined from frequency analysis for a given return period as shown in Figure (5). The time to peak flow and base time of the triangular hydrograph are calculated from equations (6) and (7). One of these hydrographs is shown in Figure (6) for return period 10^4 year. The topographic relationships for the reservoir equations (1) and (2) and equation (8) for flow over the spillway are used in the flood routing. Results of flood routing for different design and return periods are shown in table (3) and Figure (7). The existing freeboard of 3 m is added to the maximum flood level to get the dam crest level. For return period $T_r = 10^4$ year, the dam crest level is 540.6 m, 541.9 m, 543.2 m, and 545.1 m for design periods 30 year, 50 year, 70 year, and 100 year, respectively.

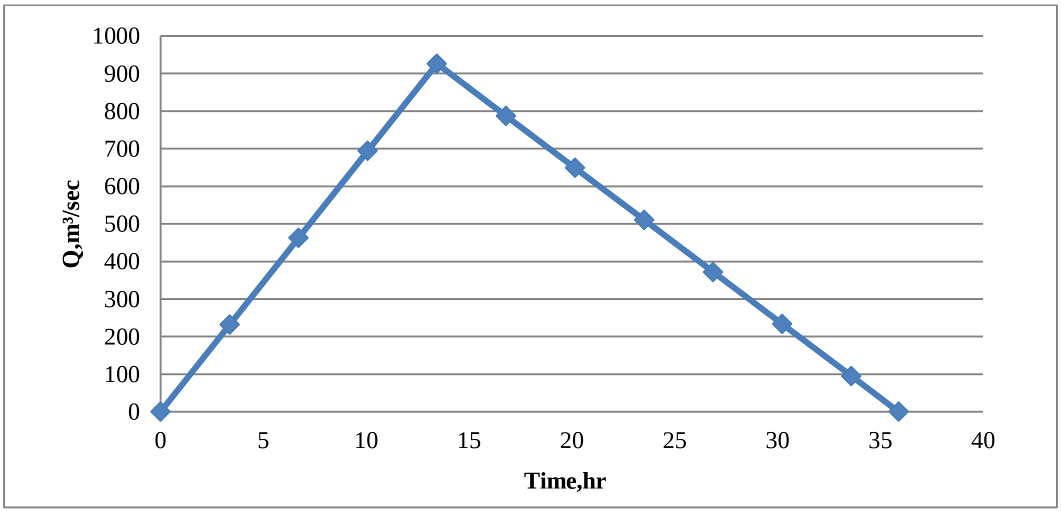

Figure (6) Inflow Hydrograph for Return period 10^4 year

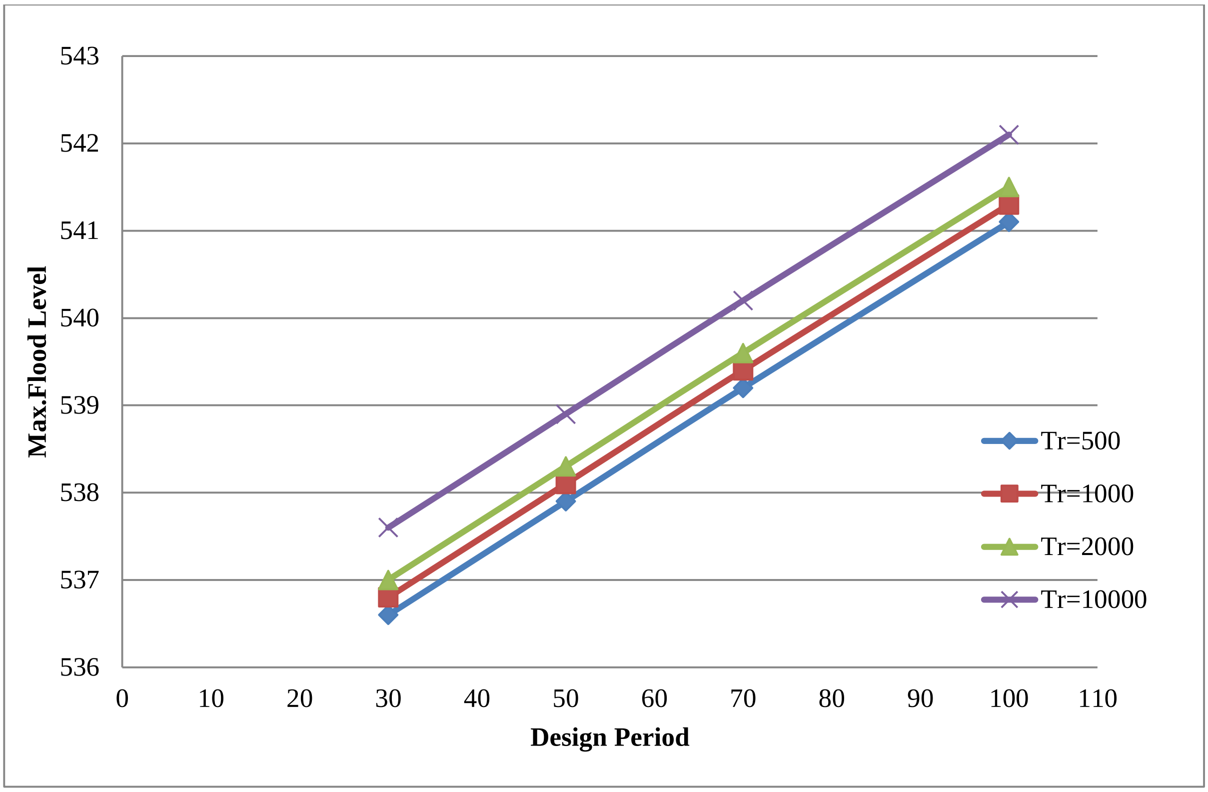

Figure (7) Maximum Flood Levels for different Return and Design Periods

Table (3)

Results of Flood Routing for Different Return and Design Periods

Design Period	F.R.L (m amsl)	Max. Flood Level (for T_r = 10^4 yr)	Dam crest level with existing freeboard = 3 m
30	535.4	537.6	540.6
50	536.7	538.9	541.9
70	538	540.2	543.2
100	539.9	542.1	545.1
Design Period	F.R.L (m amsl)	Max. Flood Level (for T_r = 2000 yr)	Dam crest level with existing freeboard = 3 m
30	535.4	537	540
50	536.7	538.3	541.3
70	538	539.6	542.6
100	539.9	541.5	544.5

Design Period	F.R.L (m amsl)	Max. Flood Level (for T_r = 1000 yr)	Dam crest level (existing freeboard = 3 m)
30	535.4	536.8	539.8
50	536.7	538.1	541.1
70	538	539.4	542.4
100	539.9	541.3	544.3
Design Period	F.R.L (m amsl)	Max. Flood Level (for T_r = 500 yr)	Dam crest level (existing freeboard = 3 m)
30	535.4	536.6	539.6
50	536.7	537.9	540.9
70	538	539.2	542.2
100	539.9	541.1	544.1

CONCLUSIONS AND RECOMMENDATIONS

The available measured data allows the estimation of reservoir water storage capacity. Using the sequent peaks method, it equals 27.69 MCM, and represents three times the existing capacity (9.3 MCM). Considering the expected sedimentation, the existing overflow spillway crest (520 m a.msl) can be raised by 15.4 m, 16.7 m, 18 m, and 19.9 m for design period 30 year, 50 year, 70 year, and 100 year respectively, and the corresponding increase in storage capacity from 9.3 MCM to 30.5, 32.4, 34.3, and 37.2 MCM. For return period 10^4 year, the existing embankment dam crest level (524 m a.msl) needs raising 16.5 m, 17.9 m, 19.2 m, and 21.1 m for design period 30 year, 50 year, 70 year, and 100 year, respectively. It is recommended that the existing roller compacted concrete (RCC) stepped spillway can be raised from the downstream side using the same materials. It is important to start raising the embankment parts of the dam using the same materials to avoid overtopping in case of reservoir flooding during construction.

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