Hydrol. Earth Syst. Sci. Discuss., 7, 1373–1405, 2010
www.hydrol-earth-syst-sci-discuss.net/7/1373/2010/
© Author(s) 2010. This work is distributed under
the Creative Commons Attribution 3.0 License.

Hydrology and
Earth System
Sciences
Discussions

This discussion paper is/has been under review for the journal Hydrology and Earth System Sciences (HESS). Please refer to the corresponding final paper in HESS if available.

Performance analysis of the proposed Reservoir Project in the State of West Bengal

D. Roy and D. Banerjee

School of Water Resources Engineering, Jadavpur University, Kolkata, India

Received: 25 January 2010 – Accepted: 30 January 2010 – Published: 17 February 2010

Correspondence to: D. Roy (mrinmoy@majumder.info)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Water is an essential and integral part of livelihood but it is becoming scarce and contaminated day by day. Moreover, due to huge population growth the demand for water is rising especially in agricultural, industries and for municipal uses. So, to meet the rising water demand, reservoirs are constructed in different parts of the country to store water during monsoon and supply it throughout the year according to the demand. The reservoir is also constructed for controlling the peak of high flood which is quite common in many places. The Dwarakeswar River in the district of Bankura in the State of West Bengal has only seasonal flow of water. In order to meet the agricultural and municipal water requirement throughout the year and also for controlling the flood, it has been proposed to construct a reservoir at Suknibasa on the river near Bankura Town. The analysis of the performance of this reservoir for meeting various demands (under historical as well as projected scenario) as well as its capability for moderating flood has been reported in the present paper. The projected scenario involves the modeling of streamflow for future time frame using the Thomas-Fiering method and the flood moderation analysis involves the estimation of design flood hydrograph for the river at Suknibasa. The study reveals that the Suknibasa reservoir is capable of meeting all demands and moderating flood for which it has been proposed to be constructed.

1 Introduction

A river is the major source of surface water from where we could get substantial quantity of water for different uses. When a barrier is constructed across some river in the form of a dam, water gets stored up in the upstream side of the barrier forming a pool of water, generally called reservoir. Reservoir is one of the most important components of a water resources development project. The principal function of a reservoir is to regulate the streamflows by storing surplus water in the high flow season, control floods, and release the stored water in dry season to meet various demands. There

CC BY

is slowdown in construction of new projects as construction cost of projects, associated rehabilitation and resettlement costs have increased manifold over the past few decades and also as environmental considerations are gaining importance. It is, therefore, imperative to assess whether the performance of these costly projects would be adequate over years before investments are made.

The simulation technique associated with reservoir operation which includes mass balance computation of reservoir inflows, outflows and change in storage, has provided a bridge from early analytical tools for analyses of reservoir systems to complex general purpose packages. Simomovic (1992) points out that concept inherent in simulation are easier to understand and communicate, allow detailed and faithful representation of a real world system's performance and can be easily combined with synthetically generated inflow sequences. Chalisgaonkar et al. (2006) reports that simulation methods are gradually improving their role with regard to influencing decisions made in the operational control of actual reservoirs.

Examples of simulation date back to the early 1950s.One of the most popular and widely used generalized reservoir system simulation models is the HEC-5 model developed by the Hydrologic Engineering Centre (HEC-5, 1982; Wurbs, 1996). Some other well known simulation models are: Acres model (Sigvaldson, 1976), Streamflow Synthesis and Reservoir Regulation (SSARR) Model (USACE, 1987), the Interactive River System Simulation (IRIS) MODEL (Loucks et al., 1989) and the Water Right Analysis Package (WRAP) (Wurbs et al., 1993). The SSARR model was applied for simulating river management activities in the Columbia River System and numerous other river systems in the United States and other countries (Ponce, 1989). The Reservoir System Simulation program, HEC-ResSim, released by the Hydrologic Engineering Center in 2007 is the "Next Generation" (NexGen) software packages of the Centre and is designed to be used to model reservoir operations of one or more reservoirs whose operations are defined by a variety of operational goals and constraints. Lund and Ferriera (1996) studied the Missouri River reservoir system and found simulation models to be superior to classical regression techniques for inferring and refining operating rules derived from deterministic DP. Jain and Goel (1977) have presented a generalized simulation model for comservation operation of a reservoir system based on rule curves. Jain and Bhunya (2009) narrated the conventional and advanced techniques of reservoir operation and investigated the susceptibility of storage reservoirs to drought. Computer models with conditional variability were also employed to study reservoir operation (He et al., 2008). The Chatfield Reservoir Reallocation Project of Colorado Water Conservation Board (2003) analyzed the feasibility study to investigate the potential for reallocation of reservoir storage space from flood control use to multi-purpose use, including up to 20 600 acre-feet for Municipal and Industrial and agricultural uses in the southern portion of the Denver Metropolitan area, Colorado. Nandalal and Bogardi (1995) presented a methodology for management of Jarreh Reservoir Project on the Shapur river in Southern Iran. Liebe et al. (2007) studied the operation of Small Reservoir Project to improve water availability and economic development in small semi-arid areas of the Volta Basin, Ghana and Burkina Faso, Ghana. Chalisgaonkar et al. (2006) developed a Decision Support System (DSS) for simulating the operation of a multipurpose multireservoir system. Roy and Bose (2001) analyzed the regulation of a multipurpose multireservoir system of the Damodar Multipurpose River Valley Project in the State of West Bengal. A computational framework based on simulation model concerning regulation of the multireservoir system (involving daily/weekly/ten-day/monthly time step) had been developed. The model had been used for evaluation of the performance of the system for various configurations and for working out of rule curve for reservoir operation. Parhi et al. (2007) studied the implications of the available chance-constrained models when modified for reservoir design and operations using the data of the Ramiala reservoir in the Brahmani basin in Orissa (India).

The present paper reports a simulation technique based analysis of the performance of a reservoir (proposed to be constructed at Suknibasa on the river Dwarakeswar, District Bankura, State of West Bengal, India) for meeting various demands (under historical as well as projected scenario) as well as its capability for moderating flood.

cc BY

The generation of projected scenario involves the modeling of streamflow for future time frame using the Thomas-Fiering method (based on Markov autoregressive model) while the flood moderation analysis involves the estimation of design flood hydrograph using storm maximization technique with Snyder's Unit Hydrograph.

It may be noted that many inflow forecasting models have been proposed for real-time reservoir operation model. The benefits deriving from their use have been shown by Yeh et al. (1982). Many researchers used autoregressive models for monthly and yearly streamflow forecasting (Hirsch, 1981). Krzysztofowicz and Watada (1986) calibrated a discrete time, finite, nonstationary Markov process for forecasting seasonal snowmelt runoff volume. McLeod et al. (1986) stated that the combination of different forecasting methods is useful for assessment of performance of reservoir operation. An autoregressive model was chosen for 10-day streamflow prediction of Tanshui River in Taiwan by Kuo et al. (1990). Mazzola (1994) modeled monthly streamflows using autoregressive Markovian Process. Ghosh (1998) generated the monthly flow data of the river Mahanadi (India) synthetically by Thomas and Fiering method and concluded that annual flow data calculated on the basis of synthetically generated discharge data compare favorably with the average figure of the observed annual discharge data. Kumar and Kumar (2006) used seasonal autoregressive moving average approaches for modeling monthly streamflow of Betwa river, India. The annual streamflow series for Godavari river at Gangapur dam site (India) was generated using Autoregressive model by Tanpure et al. (2006).

Again it may also be noted that since its inception in 1938, Snyder's method of generation of Unit Hydrograph for ungauged catchments has been used by various researches worldwide (HEC-1, 1968; Boggild et al., 1999; HEC-HMS, 2000; Das, 2000; Atre et al., 2005; Watershed Modeling System, 2009, and Subramanya, 2003). It may further be noted that Kumar et al. (2007) reported Design Flood estimation of river Tons in North India.

2 Study area

The Dwarakeswar river basin is one of the 26 river sub-basins of the State and is under the Ganga-Bhagirathi system. The basin, located between longitudes 86°31′ and 87°51′ E and latitudes 22°37′ and 23°33′ N, occupies a total area of about 4673 km^2. The river is about 220 km in length and passes through the three districts within the State namely, Purulia, Bankura and Hooghly and releases ultimately into the Rupnarayan, a right bank tributary of the Bhagirathi-Hooghly in its lower reaches (Fig. 1). The Gandheswari, Beko, Dudhbhariya, Dangra, Futiary, Arkasa, Birai are some of the prominent tributaries of the Dwarakeswar in the upper basin. Geologically, the upper Dwarakeswar basin is mainly hilly region in continuance of the Chhotanagpur plateau. The master slope of the area tends towards the South-East direction. In the extreme north-western part, towards Chhotanagpur plateau, undulations are more pronounced.

3 Data acquisition

Historical monthly rainfall data for eleven years (1990–2000) has been collected from Investigation and Planning Division, I&WD, Govt. of West Bengal, Purulia, for the raingauge stations located in the watershed and has been used to determine the mean precipitation. Historical monthly rainfall data for thirty four years (1975–2008) for the raingauge station located at Bankura has been collected from Irrigation Division, Govt. of West Bengal, Bankura. Other meteorological data such as maximum and minimum air temperature, relative humidity, wind speed, solar radiation and vapor pressure have been collected from meteorological observatory, Govt. of West Bengal, at Bankura. Discharge data at Suknibasa gauge station spanning over the year 1995–2006 has been collected from Investigation and Planning Division, I&WD, Govt. of West Bengal, Burdwan. The toposheets (73I/11, 73I/14, 73I/15, 73I/16, 73M/3 and 73M/4) have been collected from Survey of India, Govt. of India. The temporal distribution of rainfall has been collected from Investigation and Planning Division, I&WD, Govt. of West Bengal, Purulia.

4 Methodology

4.1 Performance analysis of the reservoir in meeting water demand

The Simulation operation of the reservoir for meeting conservation need is based on the following equation (HEC-5, 1982)

$$S_j = S_{j-1} + I_j + P_j - L_j - E_j - R_j \tag{1}$$

Where, S_j and S_{j-1} are the storage volumes at the end of the current month j and at the end of the previous month $(j-1)$, respectively. I_j is the volume of water flowing into the reservoir during the j-th month. P_j is the precipitation volume over the reservoir during the j-th month. L_j and E_j are the seepage loss and evaporation loss from the reservoir, respectively, and R_j is the release of volume of water from the reservoir to meet the various demands.

The work is carried out in the following steps for both historical and projected (synthetic) streamflow scenario.

4.2 Delineation of catchment of the river

Drainage network and elevation contours have been digitized using Survey of India toposheets at 1:50 000 scales using Map Window GIS software. The catchment area and length of the Dwarakeswar River upto the Suknibasa reservoir have been found to be 755.05 km^2 and 49.7 km, respectively. The average slope of the upper basin upto Suknibasa has been computed to be about 2.01 m km^{-1}.

4.3 Computation of mean precipitation by the Thiessen-polygon method

The Thiessen-polygon method has been used to determine the mean rainfall over the Dwarakeswar River basin using the monthly rainfall data available for the five raingauge stations namely Bankura, Hura, Kashipur, Susunia, Saltora (Fig. 2).

cc BY

The evaporation loss from the reservoir has been calculated from the Open water evaporation data and the seepage loss has been considered as 0.5 percent of the reservoir volume (Ramos, 1997).

4.4 Computation of historical water demand in the command area

4.4.1 Agricultural water requirement

Crop water requirement (ET_c) is calculated by the following formula (FAO Irrigation and drainage paper no. 56, 1998)

$$ET_c = K_\mathrm{c} ET_o \tag{2}$$

Where, ET_o = Reference Potential Evapotranspiration, K_c = crop factor.

The monthly meteorological data of Bankura has been used to determine the Reference Potential Evapotranspiration by the Fao Penman-Montieth based combination formula for a single reference crop. The effective rainfall has been derived using USDA, SCS Method (Food and Agricultural Organization of the United States, Irrigation and Drainage paper). The FAO methodology has been adopted for estimating irrigation water requirements for rice and all other crops which has been shown in Table 1.

The total cultivable land for Kharif and Rabi crop has been reported to be 333.35 km^2 and 21.10 km^2, respectively (Report of I&WD, Govt. of West Bengal, 1996).

4.4.2 Municipal water demand

Water demand for domestic purposes of rural and urban population of Bankura Town, Jhanti-pahari township and of the command area have been calculated on the basis of the guidelines prepared by the Expert Committee, Central Public Health and Environmental Engineering Organisation, Ministry of Works and Housing, Govt. of India (Report of Expert Committee on Irrigation, June 1987; Irrigation and Waterways Department, Govt. of West Bengal) and has been computed as 19.38 Mm^3.

4.4.3 Industrial water demand

No major or medium industry is located in the Dwarakeswar river basin. So, the water requirement for industrial purpose is not taken into account in the simulation study of the reservoir.

4.4.4 Downstream flow release to Pratappur Barrage

The flow release to Pratappur Barrage (at the confluence of the Dwarakeswar and Gandheswari rivers and over the river Dwarakeswar, downstream of Suknibasa (Fig. 2)) is also taken into account in the simulation study.

4.5 Calculation of storage volume

The storage volume of the reservoir has been calculated using Eq. (1) and the corresponding reservoir level and area of the reservoir have been calculated from the storage-elevation curve (Fig. 3) and the area-elevation curve (Fig. 4), respectively.

The reservoir storage and its corresponding volume and level for the Suknibasa reservoir have been given below:

Reservoir storage	Volume (ham)	Level (m)
Full storage	9656	120.8
Dead storage	2400	115.4
Live storage	7256	119.2
Initial storage	2400	115.4

4.6 Generation of projected (synthetic) streamflow scenario

In a statistical sense, the historical record of streamflow is a sample out of a population of natural streamflow process. If this process is considered stationary (the statistical properties such as mean, standard deviation of a series do not change with time), many series representing such samples can be formulated that will be statistically similar to the historical record. This is the basis of the synthetic technique. Thus the generated flows are neither historical flows nor a prediction of future flows but are representative of likely flows in a stream. The Markov chain model (Gupta, 1989) is one method for generating synthetic streamflow.

Thomas and Fiering used the Markov chain model for generating monthly flows by taking into consideration the serial correlation of monthly flows . The general Markov procedure of data synthesis comprises: (1) identifying the frequency distribution of the historical data, (2) determination of statistical parameters from the analysis of the historical record, (3) generating random numbers of the same distribution and statistical characteristics, and (4) constituting the deterministic part considering the persistence (influence of previous flows) and combining with the random part.

The model uses the following recursion equation:

$$q_{i,j} = \overline{q_j} + b_j \left(q_{i-1,j-1} - \overline{q_{j-1}} \right) + t_{i,j} S_j \left(1 - r_j^2 \right)^{1/2} \tag{3}$$

Where q_j and q_{j-1} are the discharge volumes during j-th and $(j-1)$-th months, respectively, $\overline{q}_j$ and $\overline{q}_{j-1}$ are the mean monthly discharge volumes during j-th and $(j-1)$-th months, respectively. S_j is the standard deviation for j-th month, r_j is the correlation coefficient between the j-th and $(j-1)$-th month, $t_{i,j}$ is the random independent variate with zero mean and unit variance. Here i is the year and j is the month.

$$b_j = r_j \left(\frac{S_j}{S_{j-1}} \right); \quad \overline{q}_j = \frac{\sum q_j}{N} \quad ; \quad S_j = \left[\frac{\sum \left(q_j - \overline{q}_j \right)^2}{(N-1)} \right]^{1/2};$$

$$r_j = \frac{\sum q_j q_{j-1} - \left(\sum q_j \sum q_{j-1} \right)/N}{\sqrt{\sum q_j^2 - \left(\sum q_j \right)^2/N} \sqrt{\sum q_{j-1}^2 - \left(\sum q_{j-1} \right)^2/N}}$$

Where N is the number of years for which the record is available.

Testing for statistical similarity of the generated flow record with the historical record involves the comparison of the mean and standard deviation of the computed streamflow series and the historical streamflow series of 12 years as given below:

$$\text{Mean (\%)} = \frac{q - q'}{q} \times 100 \tag{4}$$

Where q is the observed mean monthly discharge volume; q' is the computed mean monthly discharge volume.

$$\text{SD (\%)} = \frac{S - S'}{S} \times 100 \tag{5}$$

Where S is the Standard Deviation of the observed streamflow and S' is the standard deviation of the computed streamflow.

4.7 Indices for evaluation of the performance of the Suknibasa reservoir in meeting various water demands

The performance of the Suknibasa reservoir for both the historical and the projected scenario has been evaluated based on different indices defined below:

Time based reliability (RI1): It is the ratio of number of stages during the simulation for which demands could be met and the total number of stages in the simulation.

Average severity of duration of failure (RI2): It is the ratio of sum of number of consecutive failure stages for each individual set of failure and total number of such failure sets during the whole period of simulation. In fact it is the average duration of the period in which the system is in a failure mode.

Duration based reliability (RI3): It is the ratio of sum of number of consecutive non-failure (or success) stages for each individual set of success and the total number of such non-failure sets during the whole period of simulation. It is the average number of consecutive time steps in which the system succeeds to meet the demand.

CC BY

Mean daily deficit (RI4): It is the ratio of the sum of deficit in demand and the number of failure stages over the whole period of simulation.

Resilience (RI5): It is the longest duration of consecutive periods of failure.

RI6 is the longest duration of consecutive periods of success.

Maximum Vulnerability (RI7): It is the magnitude of the largest failure event.

Frequency of maximum vulnerability (RI8): It is the number of stages during which the largest failure event occurs.

4.8 Computation of water demand in the command area for the projected scenario

4.8.1 Agricultural water demand

The cultivable land area has been estimated to be 436.09 km^2 using the Google Earth and the Free View Software. Thus, the additional cultivable area over and above the prevailing one turns out to be 81.64 km^2 (436.09−354.45). This additional agricultural area was targeted to be brought under irrigation by the year 2014. This necessitates an annual increment of irrigated area by 20% during 2009–2014.

4.8.2 Municipal water demand

It has been reported that the rate of population growth in the State is about 15% during the last decade (Chakravarty, 1991). This rate of growth in population was adopted to project population in the Dwarakeswar river basin.

4.9 Performance analysis of the reservoir in controlling flood

This involves the estimation of design flood hydrograph and routing the same through the reservoir.

cc BY

4.10 Estimation of Design Flood

4.10.1 Generation of Unit Hydrograph by Snyder method

The Snyder's equation relates the basin lag t_p to the basin characteristics as

$$t_p = CC_\mathrm{t}(LL_\mathrm{ca})^{0.3} \tag{6}$$

Where L = basin length measured along the water course from the basin divide to the gauging station in km. L_ca = distance along the main water course from the gauging station to a point opposite the watershed centroid in km. C_t = a regional constant representing watershed slope and storage. C= a conversion constant (0.75 for SI system).

The effective rainfall duration (t_r) is given as

$$t_\mathrm{r} = \frac{t_p}{5.5} \tag{7}$$

For a non-standard rainfall duration t_R h instead of standard value t_r the basin lag is given as

$$t'_p = t_p + \frac{t_R - t_r}{4} \tag{8}$$

Where t'_p = basin lag in hours for a rainfall duration of t_R h.

The peak discharge Q_p (m^3 s^{-1}) of a Unit Hydrograph for nonstandard effective rainfall of duration t_R h is

$$Q_p = 2.78 \cdot C_p \cdot A / t'_p \tag{9}$$

Where A = catchment area in km^2 and C_p = a regional constant accounting for storage and other runoff conditions.

The time to peak of the Unit Hydrograph is given by

$$t_{pk} = \frac{t_\mathrm{R}}{2} + t'_p \tag{10}$$

The widths of Unit Hydrographs (in time units) at 50% and 75% of the peak discharge have been found for US catchments by the US Army Corps of Engineers as given below

$$W_{50} = \frac{5.87}{q^{1.08}} \tag{11}$$

and

$$W_{75} = \frac{W_{50}}{1.75} \tag{12}$$

W_{50} = width of Unit Hydrograph in hour at 50% peak discharge; W_{75} = width of Unit Hydrograph in hour at 50% peak discharge.

The time base of a Unit Hydrograph is given by Snyder as

$$t_b = 3 + \frac{t'_p}{8} \text{ days} = (72 + 3t'_p) \text{ hours} \tag{13}$$

The actual Unit Hydrograph has been drawn primarily on the basis of Q_p, t_p and t_b with the remaining values used as guidelines as has been suggested by Ponce (1989).

4.10.2 Generation of Probable Maximum Precipitation for the basin

The Probable maximum Precipitation (48 h) has been computed using flood-frequency method with $T = 1000$ years (following the Guidelines for selecting Design Floods (CWC, India)).

4.10.3 Generation of 3 hourly precipitation corresponding to Probable Maximum Precipitation for the basin

A 3 hourly rainfall distribution corresponding to Probable Maximum Precipitation has been generated using the temporal distribution of rainfall data for Bankura Station.

4.10.4 Generation of critical sequence of rainfall

The 3-hourly design excess-rainfall values of 48 h have been so arranged that the highest hourly value of the excess-rainfall is placed against the highest value of the ordinate of the Unit Hydrograph and second highest value is placed against the second highest ordinate of Unit Hydrograph and so on. The so arranged sequence is then reversed to generate the critical sequence of rainfall (Kumar, 2007).

4.10.5 Generation of design flood hydrograph

The critical sequence of excess rainfall has been applied to the Unit Hydrograph for the computation of the design direct runoff hydrograph. A constant base flow of 30 cumec (report of I&WD, Govt. of West Bengal, 1996) has been added to obtain the design flood hydrograph.

4.11 Routing the design flood through the reservoir

The generated hydrograph was routed through the reservoir and the outflow hydrograph was generated using the Modified Pul's method by the following formula:

$$\left(\frac{I_1+I_2}{2}\right)\Delta t+\left(S_1-\frac{Q_1\Delta t}{2}\right)=\left(S_2+\frac{Q_2\Delta t}{2}\right) \tag{14}$$

Where, I_1 and I_2 are the inflow rate at the beginning and at the end of the time interval Δt.

Q_1 and Q_2 are the outflow rate at the beginning and at the end of the time interval Δt.

S_1 and S_2 are the storage of the reservoir at the beginning and at the end of the time interval Δt.

cc BY

5 Results and discussion

5.1 Generation of streamflow data

5.1.1 Identification of distribution

The streamflow series was found to follow log-normal distribution- the streamflow data was found to lie within the 95% confidence level as obtained from the Chi square test.

5.1.2 Determination of statistical parameters

The mean and standard deviation of the logarithms of the historic flow series for the year 1995 to 2006 have been calculated.

The Thomas Fiering Model has been used to estimate the probable sequence of streamflow series for 20 years of the Dwarakeswar River at Suknibasa gauge station. The mean and standard deviation of the computed streamflow series for the months of June, July, August, September, October have been compared with the mean and standard deviation of the observed streamflow series of 12 years for the months of June, July, August, September, October and the percentage errors have been calculated and are shown in Table 2.

The mean of the estimated streamflow has been found to differ from the observed ones by 1.76%, 5.95%, 2.43%, 0.45% and 7.69% for the month of June, July, August, September and October, respectively, and the standard deviation of the computed streamflow varies from the observed ones by 13.38%, 9.42%, 10.72%, 15.22% and 22.81% for the month of June, July, August, September and October, respectively. The results indicate that the estimated monthly streamflow data compare favorably well with the observed data and has been used for analyzing the performance of the reservoir in projected scenario.

Ghosh (1998) generated the monthly flow data of the river Mahanadi (India) synthetically (by Thomas and Fiering method) and concluded that annual flow data calculated on the basis of synthetically generated discharge data compare favorably with the average figure of the observed annual discharge data (difference being 7.91%). Tanpure (2006) generated the annual streamflow for Godavari River (India) synthetically by Autoregressive model and concluded the suitability of the model to describe the streamflow on the basis of closeness of mean and standard deviation of generated and historical streamflow data (the discrepancy in the two mean values is 3.58%; the discrepancy in the two s.d. values is 3.68%).

5.2 Performance of the Suknibasa reservoir in meeting various demands

The values of the Performance Indices of the Suknibasa reservoir in meeting various demands for both historical (12 years) and projected (5 years) scenario are shown in the Table 3.

It may be seen from the index RI1 under sub-column 1 that the percentages of success of the reservoir in meeting the various demands like downstream flow release to Pratappur Barrage, municipal requirement and irrigation requirement are 91%, 93% and 85% in the historical scenario. The percentages of success of the reservoir in meeting the above mentioned demands are 100%, 100% and 95% respectively for the projected scenario obtained from the index RI1 under sub-column 2. The indices RI2 and RI3 shows that the average number of consecutive time steps in which the system succeeds to meet the demands is higher than the average duration of the period in which the system is in a failure mode for both the historical and projected condition. It has been found from the indices RI5 and RI6 that the longest duration of consecutive periods of success is larger than the longest duration of consecutive periods of failure for both the historical as well as projected scenario. The results indicate that reservoir is capable of meeting all the demands.

Mazzola (1994) reported the RI5 values(for deficit higher than 30%) to be 5 months for the management of Rosamarina reservoir on the San Leonardo River in Sicily.

For DVC reservoir system, India, Roy and Bose (2001) reported the RI1 value for Tilaya reservoir as 0.74, for Maithon reservoir as 0.82, for Konar reservoir as 0.61, for

Panchet reservoir as 0.91 and for Durgapur barrage as 0.96, the RI5 value for Tilaya reservoir as 273 days, for Maithon reservoir as 180 days, for Konar reservoir as 277 days, for Panchet reservoir as 80 days and for Durgapur barrage as 14 days and the RI7 value for Tilaya reservoir as 4.89 MCM, for Maithon reservoir as 39.1 MCM, for Konar reservoir as 694.56 MCM, for Panchet reservoir as 39.1 MCM and for Durgapur barrage as 122.28 MCM.

Kindler and Tyszewski (1989) in course of their study on Dobczyce reservoir supplying water to the city of Cracow in Southern Poland quoted the following reliability indices:

$$\mathrm{RI1} = 0.964, \quad \mathrm{RI5} = \text{nine 10-day period and } \mathrm{RI7} = 3.71\,\mathrm{m}^3\,\mathrm{s}^{-1}.$$

5.3 Generation of Unit Hydrograph

The Unit Hydrograph obtained by the Snyder method is shown in Fig. 5.

The time lag (t_p) and peak discharge (Q_p) obtained from the Snyder method fit well in the graph of t_p (hours) vs. Q_p (cumecs/km^2) of the Lower Ganga Plains given in the Lower Ganga Plains Sub Zone-1(g), Central Water Commission Hydrology (Regional Studies), Govt. of India.

5.4 Critical sequence of rainfall excess increment for the 2-day design storm

Based on historical data for thirty four years (1975–2008) the 2-day maximum rainfall has been computed as 59.4 cm for $T=1000$ years. It may be noted that the 2-day Probable Maximum Precipitation (PMP) of Bankura has been estimated to be 60 cm using the guide curves (prepared by IMD) showing isohyetal lines for maximum storm depths that may result from the severest storm of 2-day and 3-day duration (Garg, 1973).

5.5 Design flood hydrograph

Design flood hydrograph for the basin at Suknibasa was generated and is shown in Fig. 6.

5.6 Flood routing computation

Design flood hydrograph and outflow hydrographs from the flood routing study through the reservoir have been shown in the Fig. 6.

The result of routing the flood hydrograph through the Suknibasa reservoir shows that owing to the storage effect, the peak of the outflow hydrograph has been smaller than that of the inflow hydrograph. The peak attenuation has been estimated to be 407.03 $m^3 s^{-1}$ and the peak lag is 2 h.

6 Conclusion

- The projected runoff series for the Dwarakeswar river at Suknibasa was successfully generated by Thomas-Fiering method. The deviation of the mean of the estimated streamflow from the observed ones was found to lie in the range 0.45% to 7.69% and the deviation of the standard deviation of the estimated flow series from the observed ones was found to lie in the range 9.42% to 22.81%
- Unit Hydrograph for the basin has been generated by the Snyder method and Design flood hydrograph for the basin has been estimated. The time lag (t_p) and peak discharge (Q_p) associated with the aforementioned Unit Hydrograph fits well in the graph of t_p (hours) vs. Q_p (cumecs/km^2) of the Lower Ganga Plains given in the report on Lower Ganga Plains Sub Zone-1(g), Central Water Commission Hydrology (Regional Studies), Govt. of India
- Design Flood Hydrograph for the basin at Suknibasa was also generated.

CC BY

- The analysis of the performance of this reservoir for meeting various demands (under historical as well as projected scenario) as well as its capability for moderating flood has been carried out. The study reveals that the Suknibasa reservoir is capable of meeting all demands and moderating flood for which it has been proposed to be constructed.

Acknowledgements. The authors acknowledge their thanks to Chief Engineer and Staff Members of Bankura Irrigation Division and Bankura Municipality, Bankura, Irrigation and Waterways Directorate, Govt. of West Bengal, Purulia and Irrigation and Waterways Directorate, Govt. of West Bengal, Kolkata for providing valuable information regarding the study.

References

Atre, A. A., Aundhakar, J. D., Pawar, S. W., Sutar, N. V., and Bangal, G. B.: Hydrol. J., 28(1–2), 97–100, 2005.
Boggild, C. E., Knudby, C. J., Knudsen, M. B., and Starzer, W.: Snowmelt and runoff modelling of an Arctic hydrological basin in west Greenland, J. Hydrol. Processes, 13, 1989–2002, 1999.
Bras, R. L.: Hydrology, An introduction to hydrologic science, Addison-Wesley Publishers, 1990.
Chalisgaonkar, D., Jain, S. K., Goel, M. K., Bhunya, P. K., and Kumar, V.: Decision support system for integrated reservoir regulation, Hydrol. J., 29(3–4), 1–13, 2006.
Chatfield Reservoir Reallocation Project: Colorado Water Conservation Board, Colorado, 2003.
Chow, V. T., Maidment, D. R., and Mays, L. W.: Applied Hydrology, McGraw-Hill International Editions, 1988.
Cuenca, R. H.: Irrigation System Design, An Engineering Approach, Prentice Hall, Englewood Cliffs, New Jersey, 1989.
Clarke, R. T.: Mathematical Models in Hydrology, Irrigation and drainage paper 19, Food and Agriculture Organization of the United Nations, Rome, 1973.
Das, G.: in Hydrology and Soil Conservation Engineering, Prentice Hall of India Pvt. Ltd., New Delhi, p. 137–139, 2000.

Das, D., Roy, D., and Bose, B.: Hydrological study and water resources assessment of the Dwarakeswar River basin in West Bengal, Hydrol. J., 25(4), 49–69, 2002.

Dastane, N. G.: Effective rainfall in irrigated agriculture, FAO Irrigation and Drainage Paper, 1978.

Dwarakeswar-Gandheswari Reservoir Project: Irrigation and Waterways Directorate, Govt. of West Bengal, 1996.

Edirisinghe, N. C. P., Patterson, E. I., and Saadouli, N.: Capacity Planning for a Multipurpose Water Reservoir with Target-Priority Operation, Annals of Operation Research, 100(1–4), 273–303, 2000.

FAO Irrigation and drainage: Crop evapotranspiration, Guidelines for computing crop water requirements, paper 56, 1998.

Feldman, A. D.: HEC models for water resources system simulation: Theory and experience, Advances in Hydroscience, edited by: Chow, V. T., vol.12, Academic Press, New York, 1981.

Garg, S. K.: Hydrology and Water Resources Engineering, Khanna Publishers, 1973.

Ghosh, A. K.: Stochastic simulation of monthly stream discharge data, Proceedings All India Seminar on Development of Water Resources in India, Organized by Indian Association of Hydrologist, West Bengal Regional Centre, Kolkata, India, p. 78, 1998.

Gupta, R. S.: Hydrology and Hydraulic Systems, Prentice Hall, Englewood Cliffs, New Jersey, 1989.

He, W., Chen, J., and Dai, H.: Application of decision support system to the three Gorges Reservoir Operation, J. Hydroelectric Engg., 27(2), 11–16, 2008.

HEC-1: Flood hydrograph package, User's Manual, US Army Corps of Engineers, Hydrologic Engineering Center (HEC), USA, 1968.

HEC-5: Simulation of flood control and conservation systems, User's Manual, US Army Corps of Engineers, Hydrologic Engineering Centre, Davis, California, 1982.

HEC-HMS: Hydrologic Model System, User's Manual, US Army Corps of Engineers, Hydrologic Engineering Centre, USA, 2000.

HEC-ResSim: The Reservoir System Simulation program, User's Manual, US Army Corps of Engineers, Hydrologic Engineering Centre, USA, 2007.

Hironmoy Chakravarty: Census of India 1991, Series 26, West Bengal, Paper 1 of 1991, Provisional Population Totals, Directorate of Census Operations, West Bengal, Calcutta, 1991.

Hirsch, R. M.: Stochastic Hydrologic Model for drought management, ASCE WR, 117(1), 28–36, 1981.

cc BY

Jain, S. K.: Management of reservoir systems during drought, J. Hydrol. Res. Develop., 23, 147–165, 2008.

Jain, S. K. and Bhunya, P. K.: Reliability, resilience and vulnerability of a multipurpose storage reservoir, Hydrol. Sci. J., 53(2), 434–447, 2008.

Jain, S. K. and Goel, M. K.: Software for Reservoir Analysis, Report No. UM-1/96–97, National Institute of Hydrology, Roorkee, 1997.

Kindler, J. and Tyszewski, S.: Multicriteria evaluation of decision rules in the design of a storage reservoir, Closing the Gap Between Theory and Practice, IAHS Publication no. 180, pp. 187–201, 1989.

Krause, P., Boyle, D. P., and Bse, F.: Comparison of different efficiency criteria for hydrological model assessment, Adv. Geosci., 5, 89–97, 2005, http://www.adv-geosci.net/5/89/2005/.

Krzysztofowicz, R. and Watada, L. M.: Stochastic model of seasonal runoff forecasts, Water Resour. Res., 22(3), 296–302, 1986.

Kumar, R., Singh, R. D., Chatterjee, C., Mani, P., and Panigrahy, N.: Advance Deterministic and Probabilistic Modeling for Design Flood Estimation, Technical Journal, vol. 88, The Institute of Engineers (India), May 2007.

Kumar, M. and Kumar, D.: Seasonal ARIMA modeling of monthly streamflows J. Applied Hydrology, XIX(4), 91–98, 2006.

Kuo, J.-T., Hsu, N.-S., Chu, W.-S., Wan, S., and Lin, Y.-J.: Real Time operation of Tanshui river reservoir, ASCE WR, 116(3), 349–361, 1990.

Liebe, J., Andreini, M., van de Giesen, N., and Steenhuis, T.: The Small Reservoirs Project: Research to Improve Water Availability and Economic Development in Rural Semi-arid Areas, Cambridge Scholars Publishing, Newcastle, pp. 325–332, 2007.

Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H.: Hydrology for Engineers, SI Metric Edition, McGraw Hill Book Company, 1988.

Loucks, D. P., Salewicz, K. A., and Taylor, M. R.: IRIS: An Interactive River System Simulation Model, General Introduction and Description, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1989.

Loucks, D. P. and Dorfman, P. J.: An Evaluation of Some Linear Decision Rules in Chance-constrained Models for Reservoir Planning and Operation, Water Resour. Res., 11(6), 777–782, 1975.

Lund, J. R. and Ferreira, I.: Operating rule optimization for the Missouri River reservoir system,

cc BY

J. Water Resour. Planning and Management, ASCE, 122(4), 287–295, 1996.

Mazzola, M. R.: Multipurpose reservoir real time management by stochastic interannual forecasting model, in: Proc. The Second European Conf. on “Advances in Water Resources Technology and Management”, edited by: Tsakiris, G. and Santos, M. A., published for EWRA by A.A. Balkema, 1994.

McLeod, A. I., Noakes, D. J., Hipel, K. W., and Thompstone, R. M.: Combining hydrologic forecasts, ASCE WR, 113(1), 29–41, 1987.

Michael, A. M.: Irrigation, Theory and Practice, 2nd Edition, Vikas Publishing House Pvt. Ltd., 1978.

Mohan, S. and Srinivas, U.: An optimization Model for Drought Management, Proc. 56th Research and Development Session, Central Board of Irrigation and Power, 1991.

Nagy, I. V., Asante-Duah, K., and Zsuffa, I.: Hydrological Dimensioning and Operation of Reservoirs, practical design concepts and principles, Kluwer Academic Publishers, The Netherlands, 2002.

Nandalal, K. D. W. and Bogardi, J. J.: Reservoir Management for improving river water quality, Proc. The EWRA95 Symposium on “Water Resource Management under Drought or Water Shortage Conditions:, edited by: Tsiourtis, N. X., Water Development Department, Nicosia/Cyprus, 1995.

Parhi, P. K., Jain, S. K., and Singh, R.: A Chance-constrained optimization model for design and operation of a reservoir: a case study, Hydrol. J., 30(1–2), 87–97, 2007.

Patra, K. C.: Hydrology and Water Resources Engineering, Narosa Publishing House, 2001.

Ponce, V. M.: Engineering Hydrology, Principles and Practices, Prentice Hall, Englewood Cliffs, New Jersey, 1989.

Ramos, D. E.: Walnut Production Manual, University of California, Division of Agriculture and Natural Resources, Publication No. 3373, 1997.

ReVelle, C., Joeres, E., and Kirky, W.: The Linear Decision Rule in Reservoir Management and Design 1. Development of the Stochastic Model, Water Resour. Res., 5(4), 767–777, 1969.

Roy, D. and Bose, B.: Management of Multi Reservoir System, International Commission on Irrigation and Drainage, 1st Asian Regional Conference, Seoul, 2001.

Sigvaldason, O. T.: A simulation model for operating a multi-purpose multi-reservoir system, Water Resour. Res., 12(2), 263–278, 1976.

Subramanya, K.: Engineering Hydrology, Second Edition, Tata McGraw-Hill Publishers, New Delhi, 2002.

CC BY

Tanpure, S. N., Bote, N. L., Atre, A. A., Gorantiwar, S. D., Kareppa, S. M., and Gutal, G. B.: Generation of Annual Streamflow for Godavari River at Gangapur, Dam site with Autoregressive Model, J. Appl. Hydrol., XIX(1&2), 68–73 2006.

USACE: SSARR Users Manual:Streamflow Synthesis and Reservoir Regulation, US Army Corps of Engineers, Portland, Oregon, USA, 1987.

Viessman, W. and Welty, C.: Water Management Technology and Institutions, Harper & Row Publishers, New York, 1985.

Watershed Modeling System: http://www.ems-i.com/WMS/WMS_Overview/wms_overview.html, August 2009.

Wurbs, R. A.: Modeling and Analysis of reservoir System Operations, Prentice Hall, New York, 1996.

Yeh, W. W-G., Becker, L., and Zettlemoyer, R.: Worth of inflow forecast for reservoir operation, ASCE WR, 108(3), 257–269, 1982.

Table 1. Monthly Irrigation Water Requirement for different crops in mm.

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Paddy	0	0	0	0	0	0	221.33	71.61	163.8	0	0	0
Wheat	141.98	43.68	0	0	0	0	0	0	0	99.82	82.8	138.88
Mustard	0	0	0	0	0	0	0	0	0	0	52.2	118.32
Potato	113.68	0	0	0	0	0	0	0	0	99.82	75.6	120.28
Total	255.66	43.68	0	0	0	0	221.33	71.61	163.8	199.64	210.00	377.48

Table 2. Computed and observed mean and standard deviation.

	Jun	Jul	Aug	Sep	Oct
Observed mean	0.8671	1.6191	1.8702	1.7586	1.1894
Computed mean	0.8518	1.7154	1.8248	1.7506	1.098
Error%	1.7642	5.9469	2.4288	0.4522	7.6858
Observed S.D.	0.7519	0.4593	0.5483	0.4229	0.9121
Computed S.D.	0.6513	0.5027	0.4896	0.3585	0.7041
Error%	13.3751	9.4175	10.7156	15.2207	22.8098

Table 3. Performance Indices of the Suknibasa reservoir for the historical and the projected condition.

Demands	RI1		RI2		RI3		RI4 (ham)		RI5 (month)		RI6 (month)		RI7 (ham)		RI8	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Downstream flow release to Pratappur Barrage	0.91	1	7	0	17.5	35	197.93	0	7	0	35	35	1385.5	0	7	0
Municipal requirement	0.93	1	8	0	31.5	60	159.29	0	8	0	63	60	1284.9	0	8	0
Irrigation requirement	0.85	0.95	8	0	40	31	1596.35	1814.23	8	1	40	31	7784.78	3036.59	8	1

1 – denotes historical condition; 2 – refers to projected condition

Fig. 1. Location of the Dwarakeswar river.

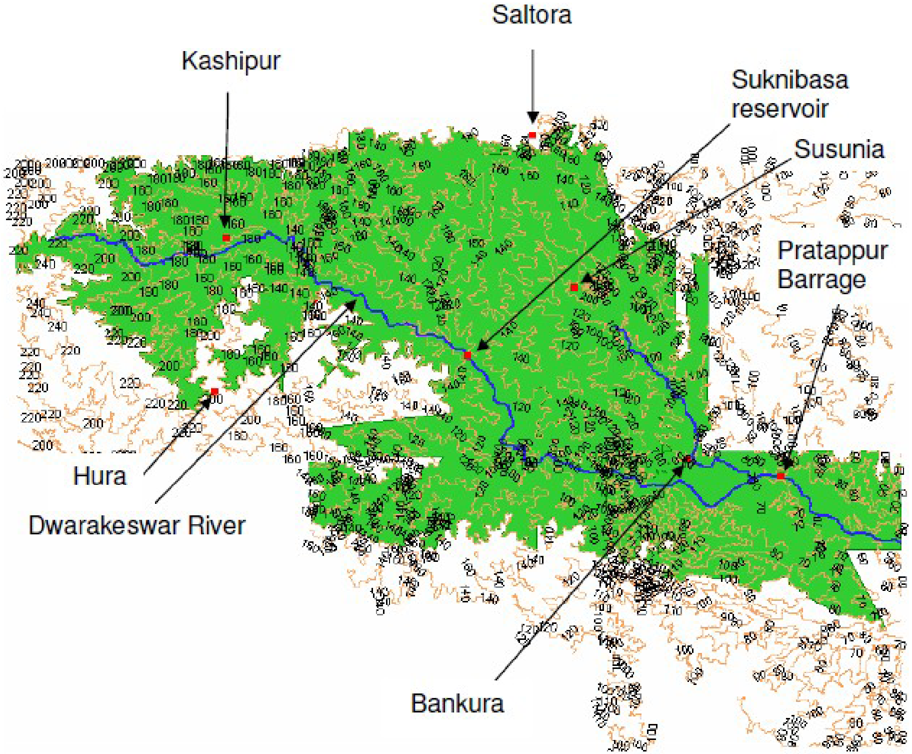

Fig. 2. Catchment area delineation of the river Dwarakeswar.

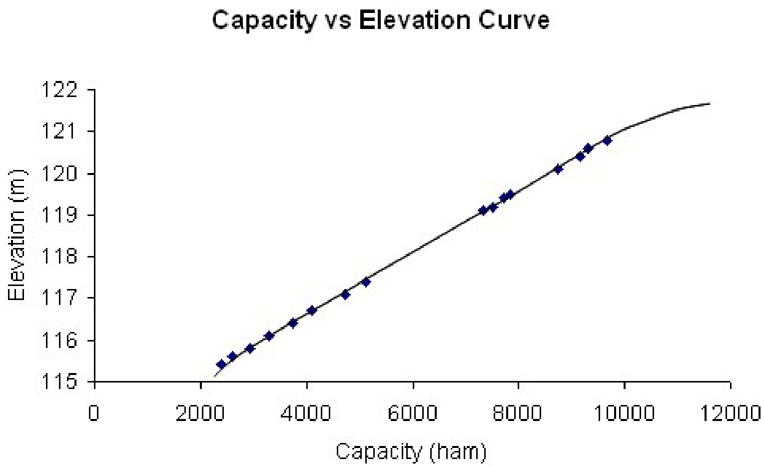

Fig. 3. Capacity vs. elevation curve.

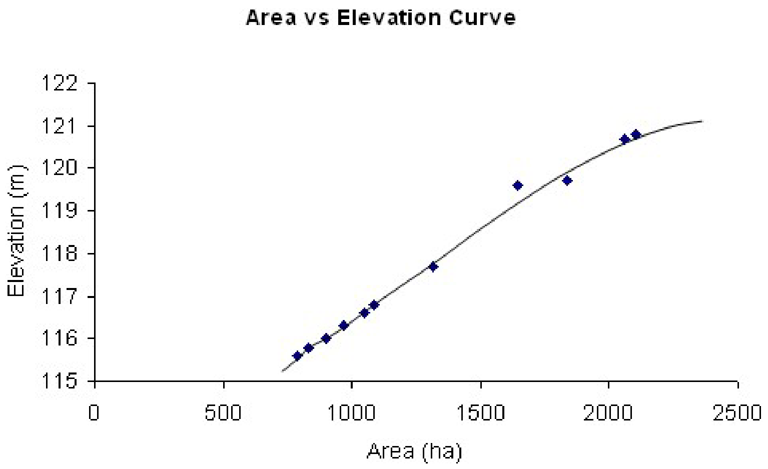

Fig. 4. Area vs. elevation curve.

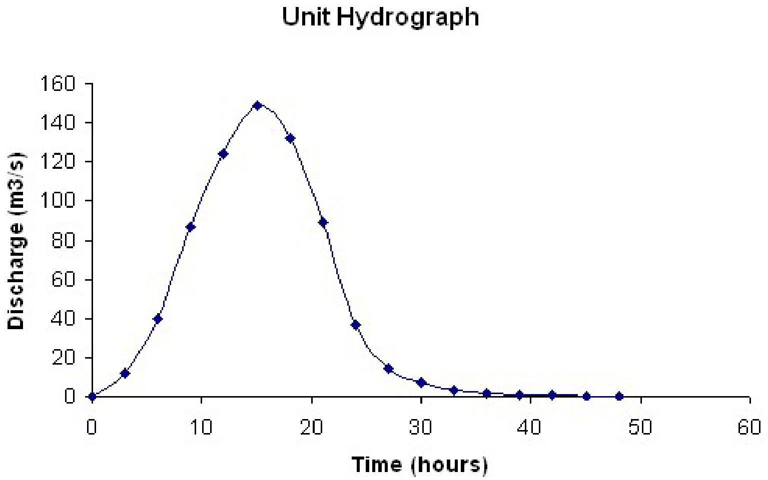

Fig. 5. Unit Hydrograph.

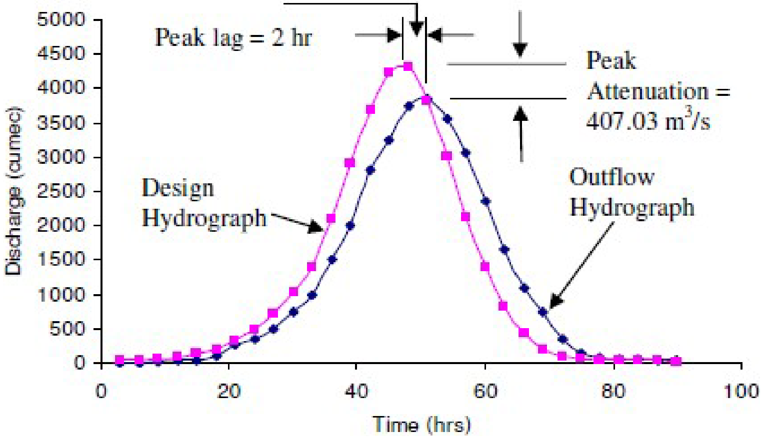

Fig. 6. Design flood hydrograph and the routed outflow hydrograph.