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COMPARISON OF ACTUAL RELEASE SCHEDULE AND OPTIMAL OPERATION OF ISAPUR RESERVOIR, INDIA

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ABSTRACT

The study investigates mathematical models on reservoir operation problem and provided a yield model (YM) based on Linear programming method for Isapur dam in India. Linear programming, ruled by evolution techniques, has become popular for solving optimization problems in diversified fields of science. Optimum yield of reservoir was calculated by yield model. In this paper the assessment of yield for a single purpose irrigation reservoir is consider. Yield model is discussed for safe reservoir yield, 75% reliable yield with failure fraction of 0.25 (75% of the annual irrigation target to be made available during failure years), 75 % reliable yield with failure fraction 0.00 (supply is restricted in failure years). The conclusion is drawn in this paper on the basis of the comparison of yield model and actual irrigation releases for single purpose irrigation reservoir.

Keywords: Yield Model, Reservoir Operation, Irrigation releases, Isapur reservoir.

INTRODUCTION

A river is the major source of water from where we get substantial quantity of water for different uses. When a barrier is constructed across some river in the form of dam, water gets stored up in the upstream side of barrier forming a pool of water, generally called reservoir. Reservoir is one of the most components of a water resource development project. The principle function of reservoir is regulate the stream flows by storing surplus water in the high flow season, control floods and releases the stored water in the dry season to meet various demands. Demands are several types as drinkable water , required water for irrigation of farms, required water for hydropower plants and required water for environmental necessaries. A river inflow to reservoir has stochastic characteristics. The continental variation, climatic variation and human activities are important factors that can vary inflows to reservoir very much.

A yield model is an implicit stochastic linear programming (LP) model that incorporates several approximations to reduce the size of the constraint set needed to describe reservoir system operation and to capture the desired reliability of target releases considering the entire length of the historical flow record. The yield model estimates over-year and within-year reservoir capacity requirements separately to meet the specified release reliability targets. Over-year capacity is governed by the distribution of annual streamflows and the annual yield to be provided. The maximum of all over-year storage volumes is the over-year storage capacity. Any distribution of within-year yields that differs from the distribution of the within-year inflows may require additional active reservoir capacity. The maximum of all within-year storage volumes is the within-year storage capacity. The total active reservoir storage capacity is simply the sum of the over-year storage and within-year storage capacities.

The concept of a yield model was introduced by Loucks et al.(1981); Stedinger et al.(1983) reviewed and compared deterministic, implicitly stochastic, and explicitly stochastic reservoir screening models. Loucks et. al. (1981) demonstrated that in several cases the yield model provides a reasonable estimate of the distribution of reservoir capacity requirements obtained with the sequent peak algorithm.

Dandy G.C. and Connarty M.C. and Loucks D.P. (1997) made a comparison of simulation, network linear programming, full optimization LP model and the LP yield model for estimating the safe yield of the Canberra water supply system consisting of four reservoirs. They pointed out that, although a simulation model will accurately assess the system yield for an assumed set of operating rules, it will not assess the maximum yield that can be achieved by adopting the best possible set of operating rules for the system.

Dahe P.D. and Srivastava D.K. (2002) developed the basic yield model and present a multiple yield model for a multiple reservoir system consisting of single purpose and multipurpose reservoirs. The objective is to achieve pre specified reliabilities for irrigation and energy generation and to incorporate an allowable deficit in the annual irrigation target. The results are analyzed for four cases. the real shortfalls between demand and flow are encountered during certain seasons or months of the year whereas on a year by year basis , the total demand is much lower than the minimum annual flow in the river. Such reservoirs are known as within-year systems.

Srivastava D.K and Taymoor A. Awachi (2009) develops nested models were applied in tandem using linear programming (LP), dynamic programming (DP), artificial neural networks (ANN), hedging rules (HRs), and simulation. An LP-based yield model(YM) has been used to reevaluate the annual yields available from the Mula reservoir for water supply and irrigation.

This study presents a methodology to optimize the design of the single reservoir irrigation system by taking monthly inflow and initial storage and tries to predict the maximum possible releases using Linear programming based Yield model. The specific objectives of the present study can be stated as fallows:

1. To develop a Linear Programming based yield model for reservoir operation for a monthly time step.
2. Comparison of yield model and actual irrigation releases for single purpose irrigation Isapur reservoir.
3. To draw the conclusions from the interpretation of results obtained.

Reservoir Yield Model

The conceptualisation and details of the yield model on which the present model development is based are presented in Loucks et. al. (1981, pp 339-353, 368-371). When reservoir yield with reliability lower than the maximum reliability is to be determined, the extent of availability of yield (or the allowable deficit in yield) during failure years can be specified. This is achieved by specifying a failure fraction for the yield during the failure years. The factor $\theta_{p,j}$ is used in the model to define the extent of available yield during failure years. The objective of this model is to maximize the yield for given capacity of the reservoir. Let p denotes the exceedence probability for the yield. The index j refers to a year and index t refers to a within-year period. In this model only the firm yield is used.

The yield model is given by Dahe and Srivastava (2002) to determine single yield from a reservoir is as follows.
The formulation of the yield model is as follows:

Objective function

Maximize $Oy^{f,p}$ (1)

Constraint

1. Over-year storage continuity

$$S^{o}_{j-1} + I_j - \theta_{p,j} Oy^{f,p} - Sp_j - El_j = S^{o}_j \qquad \forall j \qquad (2)$$

The over-the-year capacity is governed by the distribution of annual stream flows and the annual yield to be provided. The maximum of all the over-the-year storage volumes is the over-the-year storage capacity. It is possible to specify a failure fraction to define the allowable deficit in annual reservoir yield during the failure years in a single-yield problem. In the above equation, $Oy^{f,p}$ is the safe (firm) annual yield from reservoir with reliability *p*. S^{o}_{j-1} and S^{o}_{j} are the initial and the final over-the-year active storages in year j, respectively; I_j is the inflow in year j; $\theta_{p,j}$ is the failure fraction defining the proportion of the annual yield from reservoir to be made available during the failure years to safeguard against the risk of extreme water shortage during the critical dry periods ($\theta_{p,j}$ lies between 0 and 1, i.e., for a complete failure year $\theta_{p,j} =0$, for a partial failure year $0 < \theta_{p,j} <1$, and for a successful year $\theta_{p,j} =1$); Sp_j excess release (spills) in year j; and El_j = evaporation loss in year j.

2. Over-year active storage volume capacity

$$S^{o}_{j-1} \leq Y \qquad \forall j \qquad (3)$$

The active over-year reservoir capacity (Y) required to deliver a safe or firm annual yield.

3. Within-year storage continuity

$$S^{w}_{t-1} + \beta_t \left(Oy^{f,p} + \sum_t El_t \right) - Oy^{t}_{f,p} - El^{t} = S^{w}_{t} \qquad \forall t \qquad (4)$$

Any distribution of the within-the-year yields differing from that of the within-the-year inflows may require additional active reservoir capacity. The maximum of all the within-the year storage volumes is the within-the-year storage capacity. In the above equation, S^{w}_{t-1} and S^{w}_{t} are the initial and the final within-the-year active storages at time *t*; β_t is the ratio of the inflow in time *t* of the modeled critical year of record to the total inflow in that year; and El_t is the within-the-year evaporation loss during time *t*. The inflows and the required releases are just in balance. So, the reservoir neither fills nor empties during the critical year.

4. Definition of estimated evaporation losses

$$E1_j = E0 + \left[S^{0}_{j-1} + \sum_{t} \left(\frac{S^{w}_{t-1} + S^{w}_{t}}{2} \right) \gamma_t \right] El^{r} \qquad \forall_j \qquad (5)$$

Estimated annual evaporation losses from reservoir.

5. Definition of estimated evaporation losses

$$E1^{t} = \gamma_t E0 + \left(S^{o}_{cr} + \frac{S^{w}_{t-1} + S^{w}_{t}}{2} \right) \gamma_t El^{r} \qquad \forall_t \qquad (6)$$

The initial over year storage volume in the critical year S^{o}_{cr} is assumed to be zero.

Estimated within-the-year evaporation losses from reservoir.

6. Total reservoir capacity

$$Y + S^{w}_{t-1} \leq Ya \qquad \forall_t \qquad (7)$$

Sum of the over-the-year and the within-the-year storage capacities is equal to the active storage capacity of the reservoir.

7. Proportioning of yield in within-year periods

$$Oy^{t}_{f,p} = K_t \left(Oy^{f,p} \right) \qquad \forall_t \qquad (8)$$

K_t defines a predetermined fraction of reservoir yield for the within-year yield in period t.

The equation 1 to 8 presents the single reservoir yield model.

SYSTEM DESCRIPTION: ISAPUR RESERVOIR

The Penganga River is the largest southern flowing river in the Godavari Basin located in Akola, Buldhana, Hingoli, Parbhani, Nanded, Yeotmal districts of Maharashtra states in INDIA. The system of Upper Penganga Project- Isapur Reservoir is considered in this study. It is the major irrigation reservoir with live capacity of 958.43 MCM and Gross Storage capacity of reservoir is 1241.43 MCM. The monthly flow data of 28-years (1982-2009) for Upper Penganga reservoir- Isapur Dam is considered for analysis Table 1 is the silent features of Upper Penganga Project- Isapur reservoir.

Table 1. **Silent features of Upper Penganga Project- Isapur reservoir**

Scope of Scheme	Irrigation Purpose
Location	Penganga river at Isapur
Catchment area	4636 Sq Km
Mean annual inflow (1982-2009)	670.98 MCM
Gross storage capacity	1241.43 MCM
Capacity of Live Storage	958.43 MCM
Capacity of Dead Storage	283.00 MCM

28 years historic inflow data for the system considered is available as shown in Figure 1, the maximum inflow of river 3179.05 MCM was recorded in the year 1988 and minimum inflow was 88.70 MCM was recorded in the year 2004.

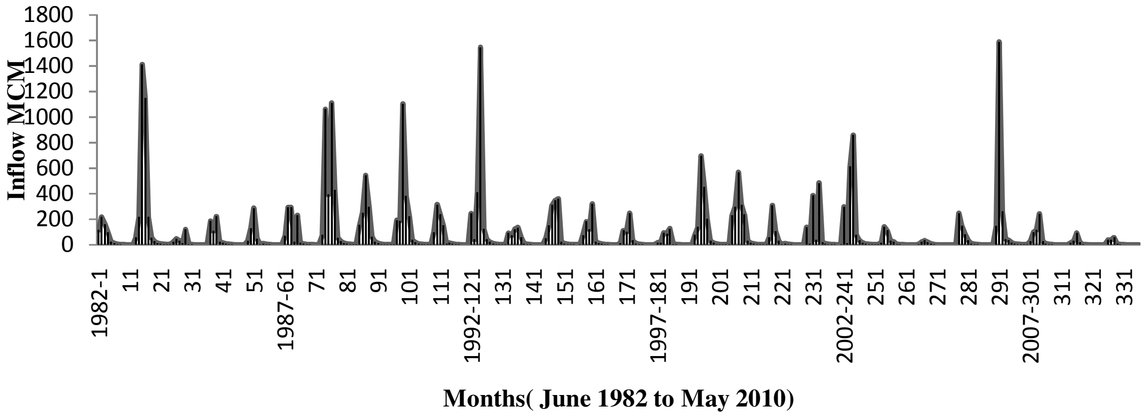

Figure: 1 Penganga river Inflow at Isapur Reservoir

Irrigation parameters (K_t) of Isapur Reservoir

The monthly proportions of the annual irrigation targets (K_t values) are worked out by considering the cropping patterns and irrigations intensities recommended by the agricultural officer. K_t defines a predetermined fraction of reservoir yield for the within-year yield in period t. The K_t values are given in Table 2 .and shown in Figure 2 .

Approximation of critical within-year inflows (β_t) values of Isapur Reservoir:

β_t based on average monthly flows. The β_t values based on average monthly flows for reservoir are given in Table 2 and shown in Figure 3.

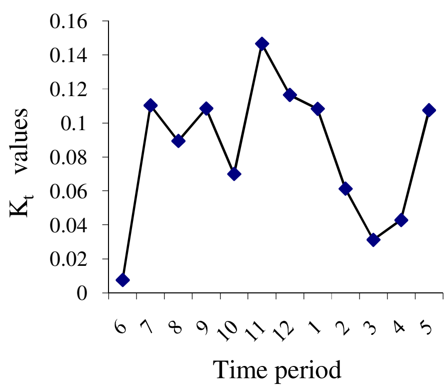

Figure: 2. Values of K_t for UPP Isapur reservoir

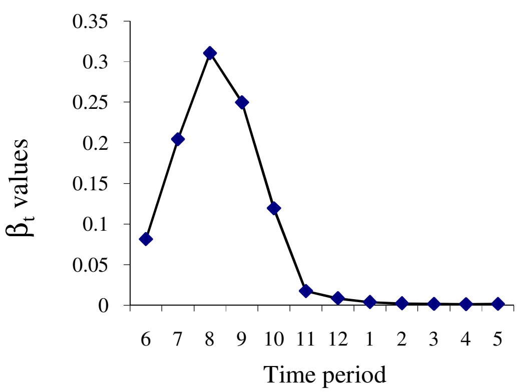

Figure: 3. Values of β_τ for UPP Isapur reservoir

Evaporation parameters of Reservoir γ_t :

The average monthly evaporation depth at all the reservoirs is obtained from the Water Resources Department and available project reports. The evaporation volume loss due to dead storage E0= 64.67 is obtained by product of the average annual evaporation depth and the area at dead storage elevation for respective reservoirs. The storage-area and storage-elevation relationship is taken for study. A linear fit for the storage-area data for each reservoir above the dead storage is obtained from the storage area relationship. The evaporation volume loss rate El^r = 0.1172 is obtained by taking the product of the slope of the area elevation curve linearized above dead storage and the average annual evaporation depth at respective reservoirs. The parameter γ_t (the fraction of the annual evaporation volume loss that occurs in within-year period t) is computed by taking the ratio of the average monthly evaporation depth to the average annual evaporation depth at respective reservoirs. The values of the γ_t are given in the Table 2 and shown in Figure 4.

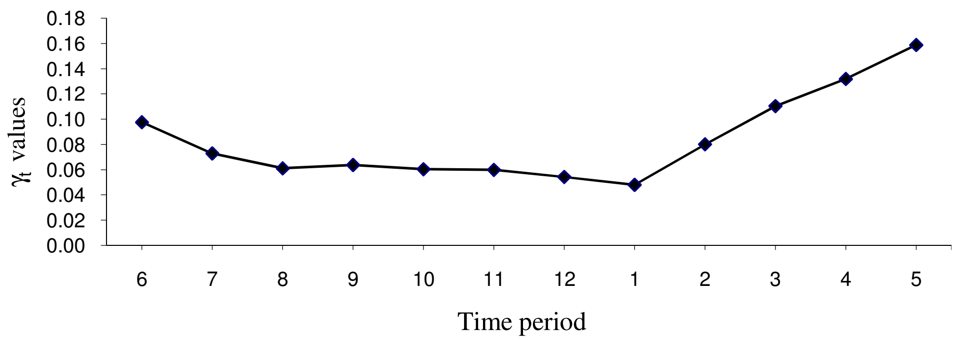

Figure : 4 Values of γ_t for UPP Isapur reservoir

Table: 2 within-year inflow approximation, Irrigation and evaporation parameters used in the yield model for Isapur Reservoir in Penganga river.

Month	June	July	August	September	October	November
β_t	0.0812	0.2044	0.3105	0.2498	0.1193	0.0172
γ_t	0.0976	0.0729	0.0611	0.0638	0.0604	0.0600
K_t	0.0076	0.1103	0.0894	0.1085	0.0700	0.1466
Edepth (m)	0.1847	0.1380	0.1156	0.1207	0.1144	0.1135
Month	December	January	February	March	April	May
β_t	0.0083	0.0037	0.0020	0.0013	0.0011	0.0012
γ_t	0.0544	0.048	0.0802	0.1109	0.1319	0.1588
K_t	0.1165	0.1083	0.0613	0.0312	0.0428	0.1075
Edepth (m)	0.1029	0.0910	0.1517	0.2088	0.2495	0.3004

ANALYSIS AND RESULTS

Application of the Yield Model in Isapur reservoir:

The observed historical inflows for 28 years (1982-2009) at the Isapur reservoir were used in computation of the yields from the reservoir with an active capacity of 958.43 MCM (project capacity). Out of these a set of 6 lowest flow years (≈ 25 % of the years) were assumed as the failure years, determined by the modified method of determining failure years by yield model. Thus remaining 22 years were successful years representing 75% annual project reliability. The six failure years are (22^{nd}, 23^{rd}, 24^{th}, 26^{th}, 27^{th} and 28^{th}) 2003, 2004,2005,2007,2008 and 2009. With the provision of $\theta_{p,j}$, the extent of failure in the annual yield from the reservoir during failure years was monitored as clear guidelines were not established for deciding its value. The value of $\theta_{p,j}$ for the project was determined using the YM with an objective to minimize its value. In single purpose reservoir, irrigation originally being the main project target was considered as a single yield or firm yield from the reservoir.

The annual project reliability for irrigation was kept equal to 75%. The value of $\theta_{p,j}$ was found to increase with the decrease in the annual yield from the reservoir.

For Isapur reservoir capacity of 958.43 MCM, yield is found out for Safe reservoir yield ($\theta_{p,j}$=1), $\theta_{p,j}$=0.25, $\theta_{p,j}$=0.50 and $\theta_{p,j}$= 0.00 respectively and calculated annual yield of reservoir by yield model is 364.20, 454.38, 527.85 and 527.85 MCM respectively.

As per yield model analysis the firm yield is found that for 75 % reliability with 50 % allowable deficit ($\theta_{p,j}$=0.50) and 75 % reliability with 100% allowable deficit($\theta_{p,j}$=0.00) is same as 527.85 MCM, The value of $\theta_{p,j}$ adopted for the project was 0.5, this gives less spill and higher utility of flow. Hence for the critical periods we can achieve at least 50 % of irrigation target releases. Within-period water releases are shown in table 3.

Table: 3. Representing the monthly water releases for irrigation by approximate YM.

Month	June	July	August	September	October	November
Safe Reservoir Yield	2.75	40.16	32.57	39.52	25.49	53.38
$\theta_{p,j}$ =0.25	3.43	50.10	40.63	49.31	31.80	66.60
$\theta_{p,j}$ =0.50	3.99	58.20	47.20	57.29	36.95	77.37
$\theta_{p,j}$ =0.00	3.99	58.20	47.20	57.29	36.95	77.37
Month	**December**	**January**	**February**	**March**	**April**	**May**
Safe Reservoir Yield	42.43	39.42	22.31	11.35	15.58	39.20
$\theta_{p,j}$ =0.25	52.93	49.18	27.84	14.17	19.44	48.90
$\theta_{p,j}$ =0.50	61.49	57.14	32.34	16.46	22.58	56.81
$\theta_{p,j}$ =0.00	61.49	57.14	32.34	16.46	22.58	56.81

Comparison of YM and Actual Releases in Isapur Reservoir:

The main objective is to compute the yield that should be released to fulfill the total demand. Comparison of actual demand, releases and yield which we are getting from the model used are as follows. Yield model based on the monthly inflow and monthly irrigation demands of the reservoir operation system is considered for the comparison.

Table 4: Values of Actual Demand, Actual releases and Yield Model (YM with 75% reliable $\theta_{p,j}$=0.50)

Month	YM	Demand	Actual Water Releases in years 1999 to 2009											Average Water release
			99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	
June	3.99	5.66	1.306	1.666	1.646	1.871	1.276	0.393	1.030	1.362	1.483	1.271	0.791	1.281
July	58.20	82.59	0.201	1.257	0.254	0.289	0.197	0.061	0.159	0.210	1.229	0.196	0.178	0.385
Aug	47.20	66.98	0.196	0.250	1.747	0.281	0.192	0.059	0.155	0.205	0.223	0.191	0.221	0.338
Sept	57.29	81.29	0.181	0.231	0.228	0.259	0.177	0.054	0.143	0.189	0.205	0.176	0.171	0.183
Oct	36.95	52.43	0.176	0.224	0.221	0.252	0.172	0.053	0.139	0.183	1.200	0.171	0.171	0.269
Nov	77.37	109.79	55.835	64.837	64.064	76.816	41.673	15.276	40.096	57.020	54.735	49.467	0.205	47.275
Dec	61.49	87.26	68.814	87.768	86.221	98.569	67.241	22.679	54.277	71.771	82.153	66.962	1.139	64.327
Jan	57.14	81.08	64.040	84.680	83.706	91.731	71.577	21.245	52.512	66.792	72.733	62.317	0.503	61.076
Feb	32.34	45.89	61.342	80.616	79.607	95.028	67.826	18.937	50.328	64.193	66.347	64.557	8.380	59.742
March	16.46	23.36	41.580	48.033	45.400	59.559	40.630	13.495	28.796	38.367	55.224	40.461	8.066	38.146
April	22.58	32.05	51.716	65.960	65.174	70.077	46.534	11.541	44.791	53.938	51.735	50.324	0.774	46.597
May	56.81	80.61	47.144	65.129	66.412	67.528	46.066	14.167	37.184	55.170	58.543	45.875	46.646	49.988
Yield	527.85	748.99	392.531	500.651	494.680	**562.260**	383.561	117.960	309.610	409.400	445.810	381.968	**67.245**	369.607

Table 2 gives the output of the model used for 75 % reliable yield as well as demand and actual releases in the years which are considered. The data available of only 11 years is used for comparison. As per the Table no. 4 the actual releases from the reservoir is maximum 562.260 MCM in the year 2002-2003 and minimum is 67.245 MCM in year 2009-2010. Actual releases are not constant for the years considered for comparison and some of the years are near to 75% reliable yield i.e 536.45 MCM in years 2000-01, 2001-2002, and 2002-2003. Whereas the actual releases are very less in the remaining years than the 75 % reliable yield by yield model analysis. Because of which the average water released is very less as compared to 75 % reliability yield.

Figure 6 shows comparison between monthly water releases, monthly demand and monthly yield by yield model . From the figure it is very clear that in the month of June, December and January the reservoir releases are near to the yield model, where as the actual demand is very large as compared to the actual releases from the reservoir except in the month February, March and April. It can be seen from the Figure 5 that the releases are negligible in the period of Kharif Crop i.e June, July, August, September and mid of October. Whereas the releases are more in the period of Rabbi Crop (i.e from October to February) and in Hot Weather crop period (i.e from February to May). As per project report they have considered releases in the month of June to October but actual releases are negligible considering due to monsoon periods.

Actual releases are considered as constant fixed quantity depending upon local demand for irrigation purposes and not on climatological conditions or crop variations that's why these actual irrigation releases are not equal to the demand.

The Yield model can be used for yield assessment with specified reliabilities and thus assists in the effective management and design of irrigation reservoir system. Yield model provides a better alternative to the deterministic full optimization model by the way of reduction in size and sufficiently accurate results. It also allows determination of annual yield with a given reliability less than the maximum reliability. There is also a provision of determining the percentage of annual yield to be supplied during failure years.

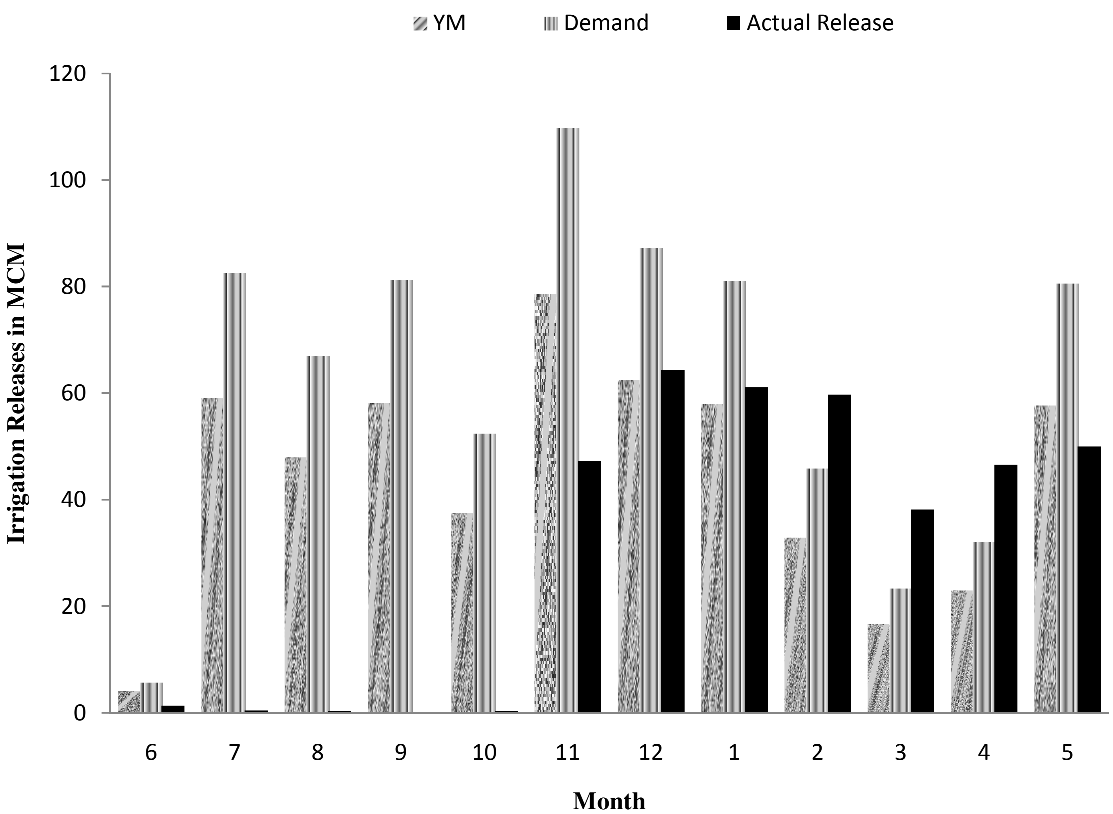

Figure: 5 Comparison of Actual demand, Actual Releases and Yield Model

CONCLUSION

The Isapur reservoir is analysed with the yield model to find their annual irrigation targets. The yield model employs monthly flows for 28 years data and is capable of permitting shortages in the annual targets of failure years. Reservoir is analyzed to find its annual irrigation targets with 75 % annual project dependability with failure fractions of zero, 0.25, 0.50 and 0.00. The failure years (22^{nd}, 23^{rd}, 24^{th}, 26^{th}, 27^{th}, and 28^{th}) 2003, 2004, 2005, 2007, 2008 and 2009 are maintained in all the analysis. As per yield model analysis the firm yield is found that for 75 % reliability with 50 % allowable deficit and 75 % reliability with 100% allowable deficit is same as 527.85 MCM, hence for the critical periods we can achieve at least 50 % of irrigation target supply of the above yield i.e 263.92 MCM.

It can be concluded that yield model performs better than the actual irrigation release. The Yield model gives accurate result by considering the monthly evaporation without increasing the size of the model. There is also a provision of determining the percentage of annual yield to be supplied during failure years.

The choice of method of analysis and model shall depend upon factors like the nature of study, its purpose and the size of problem. Yield model is relatively superior as it can consider the reliability of annual yields as well as the allowable deficit during failure years. The simulation model improves results of optimization model. Therefore using of simulation model is necessary after optimization.

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