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Full Length Research Paper

Assessment of safe reservoir yield by full optimization model by linear programming method

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This study determines a deterministic distribution of future water storage shortages, based on the known existing demands and the historical data. The data used for this study is the historical monthly flow data for 28 years of the Upper Penganga Project- Isapur reservoir in the Godavari river basin in Maharashtra, India. It is major irrigation reservoir with live capacity of 958.43 MCM and for this given capacity the safe yield was determined. The objective function is to maximize the annual safe reservoir yield. Decision variables were selected as released for irrigation and other demands (industrial and municipal), from the reservoir. A simulation programme has been developed with continuous comparison on the basis of the information obtained from the linear programming model. Hence based on the present study it is concluded that full optimization model could perform better if applied in real world operation of the reservoir.

Key words: Linear programming, simulation model, upp-isapur reservoir.

INTRODUCTION

Deterministic models (full optimization) for river basin system planning do not explicitly consider uncertainty in hydrologic variables or model parameters. As such deterministic model provide a limited representation of planning and management problems. For the preliminary analyses of alternative plans prior to more detailed stochastic optimization or simulation study, deterministic models using selected values of uncertain inputs, parameters, and variables can be useful. The deterministic model assumes that the unregulated stream flows at any site in the basin in any time period equals the historical average or some critical value for that site and period. This assumption ignores the natural variability of such flows and the need to consider over-year as well as within-year active reservoir storage capacity requirements. This stream flow variability often justifies active reservoir storage capacity even though it is not required to regulate average within-year flows. Deterministic models based on average values of inputs, (such as stream flows) are usually optimistic. System benefits are overestimated, and costs and losses are under estimated, if they are based on the expected values of each input variable instead of the probability distribution describing those variables. Hence for preliminary identification of efficient project design and operating policies prior to a detailed simulation study, deterministic models are of limited value. It is because of these limitations that many probabilistic and stochastic planning models have been developed to account for hydrologic uncertainty. In spite of this added complexity, this model steel serve only as a means of screening a wide range of design and operating policy alternatives prior to a more detailed simulation study.

If there are minimum requirements for the volume to be supplied on the monthly basis, the additional of the within-year constraints is necessary as an analysis of a system based only on an annual time period, which will result in an optimistic estimation of the safe yield. The number of constraints needed to model a particular system is reduced substantially for the full optimization model. An alternative modelling approach for reservoir planning and operation is one that emphasizes the yields that can be achieved, and their reliabilities, with a given stream flow sequence. Chaturvedi and Srivastava (1981) described a sequential iterative modelling process in

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which deterministic linear programming (LP) models were coupled with simulation to obtain optimal design alternatives considering six major reservoirs for Narmada river basin in India. Two types of LP models were used. Simulation model continued screening on the basis of information obtained from LP models to find near optimal solutions. This study is based on the report of the Narmada water resources development committee 1965. Loucks et al. (1981) developed the yield model which is a general purpose implicitly stochastic 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 target releases. Loucks and Sigvaldson (1982) summarized generally used reservoir operating rules. For reservoir in parallel water is discharged first from reservoirs with relatively large drainage area per unit storage volume capacity**.** Dandy et al. (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.

Mathematical programming techniques become popular for reservoir planning and operation. Related literature is available. An excellent review of the present topic is given by Yeh (1985), followed by Simonovic (1992), Wurbs (1993) and Despic and Simonovic (2000) along with simulation studies, LP, dynamic programming (DP) and non linear programming (NLP) which are the most popular techniques.

Simulation models closely represent the realistic situations and many researchers highlighted that simulation modelling is comparatively simple and reservoir managers are willing to accept the models even though they may not guarantee an optimal solution. However in modelling with simulation, needs to develop computer codes and number of trials are required. The earliest simulation model associated with a system of reservoir, appearing in the literature seems to be study performed by United States army corps of engineers in 1953 for an operational study for six reservoirs on the Missouri river (Hall and Dracup, 1970).

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 full optimization model. The specific objectives of the present study can be stated as follows:

(1) To develop a linear programming based full optimization model for reservoir operation for a monthly time step.
(2) To simulate the reservoir operation considering the mass balance of the single reservoir system and continuity in flows during successive months and compare with full optimization model.
(3) To draw the conclusions from the interpretation of results obtained.

METHODOLOGY

The uniform rate at which water can be drawn from the reservoir throughout a period of specified severity (dry period) is often referred to as the “firm yield” or “safe yield”. Firm yield for Isapur reservoir system was determined by using the historical records of stream flow.

The firm or safe yield is 100% reliable only if in future years of reservoir operation, no low flow occurs which will be more extreme than those, which occurred, in the historic record. Hence associated with any historic yield is a probability that yield can be provided in any future year by a given size reservoir with a particular operation policy. If no reservoir is built to increase the yields downstream of the reservoir site, the historic firm yield is the lowest flow on record.

Deterministic continuous LP model (DCLP) – full optimization model

Storage capacity requirements can be obtained by minimizing the total capacity Ya subject to continuity and capacity constraints for every within year period in every year. This model is as shown in Equations 1 to 3 for each period t in each year y, which is called, the *“complete yield model”*.

Minimize Ya (1)

Subject to

$$S_{j,\,t-1} + I_{j,\,t} - Oy^{t}_{f,\,p} - Sp_{j,\,t} = S_{j,\,t} \quad \forall_{j,} \tag{2}$$

$$S_{j,\,t-1} \leq Ya \qquad \forall_{j,\,t} \tag{3}$$

In Equation 2 if t is the final period in year j, the next period is t = 1 in year j+1, or year 1 if j is the last year of record.

The number of continuity and reservoir capacity constraints in this model can become very large when a large number of years and within year periods are considered. This is especially true if a number of reservoir sites are being considered, since each reservoir site requires an additional set of constraints. However, examination of solutions from above reservoir storage models shows that it is only a relatively short sequence of flows within the total record of flows that generally determines the required active storage capacity in a reservoir. This critical drought period is often used in engineering studies to estimate the “firm” or “safe” yield of any particular reservoir or a system of reservoirs. Even though the severity of future drought is known, many people accept the traditional practice of using the critical drought period for reservoir design and operation studies on the assumption that having observed such an event in the past, it is certainly possible to experience similar conditions in the future (Hall and Dracup, 1970).

Incorporation of evaporation losses

The approximate expected storage volume in any period t in year j can be defined as the initial over-year volume $S_{j,\,t-1}$ plus the estimated average within-year volume $\frac{s_{j,t-1} + s_{j,t}}{2}$

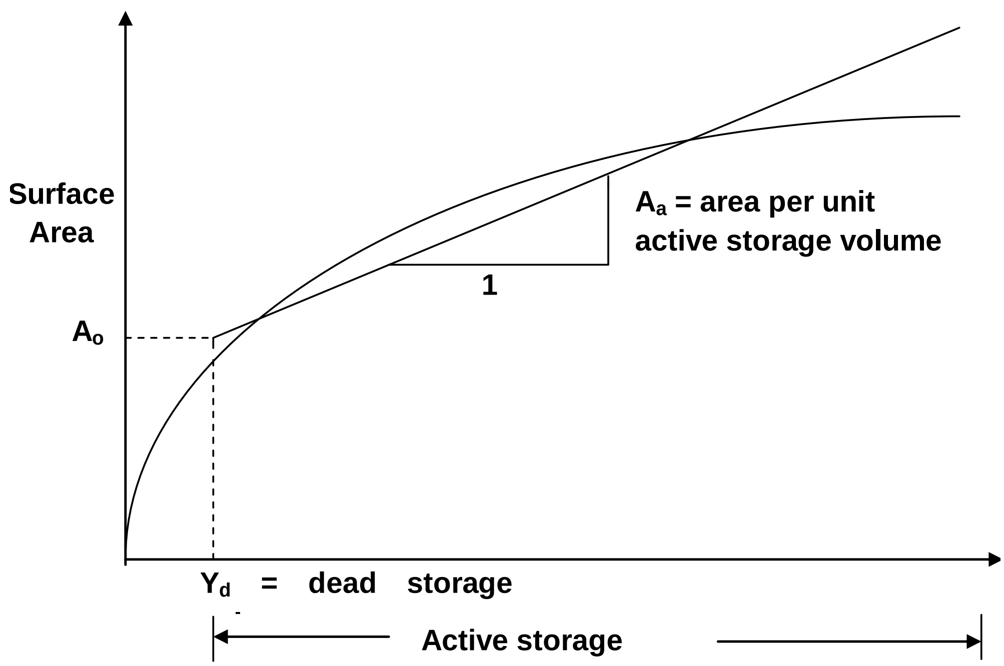

Figure 1. Storage area relationship and approximation of surface area per unit active storage volume.

The annual evaporation volume loss EL_j in each year j can be based on these average storage volumes. The storage area relationship and approximation of surface area per unit active storage volume is shown in Figure 1.

Using the average annual depth of evaporation,

El^r = A_a × average annual depth of evaporation, and
E0 = A_0 × average annual depth of evaporation.

Where,

El^r = Average annual volume loss rate per unit of active storage volume, and
E_0 = Average annual fixed evaporation volume loss due to dead storage.
A_0 = Surface dead storage area.
A_a = Area per unit active storage volume above A_0.

Formulation of the deterministic continuous LP model – Full optimization model

Objective function maximize $Oy^{f,p}$ Constraint

1. Storage continuity (monthly time period)

$$S^{o}_{j,t-1} + I_{j,t} - K_t Oy^{f,p} - Sp_{j,t} - El^{t} = S^{o}_{j,t} \quad \forall_{j,t} \tag{4}$$

2. Active storage volume capacity (monthly time period)

$$S_{j,t-1} \leq Ya \quad \forall_{j,t} \tag{5}$$

3. Definition of estimated evaporation losses

$$E1^{t} = \gamma_t E0 + \left(\frac{S_{j,t-1} + S_{j,t}}{2}\right) \gamma_t El^{r} \quad \forall_t \tag{6}$$

4. Proportioning of yield in within-year periods

$$Oy^{t}_{f,p} = K_t \left(Oy^{f,p}\right) \quad \forall_t \tag{7}$$

Where,
$O_y^{f,p}$ = Annual reservoir firm reservoir yield with reliability p.
$Oy^{t}_{f,p}$ = Firm yield in period t

Sp_j = Excess release in within-year period.

Ya = Total active storage capacity of reservoir.
K_t = Percentage fraction of annual irrigation target in period t.
γ_t = Fraction of the annual evaporation volume loss from reservoir for period t.

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

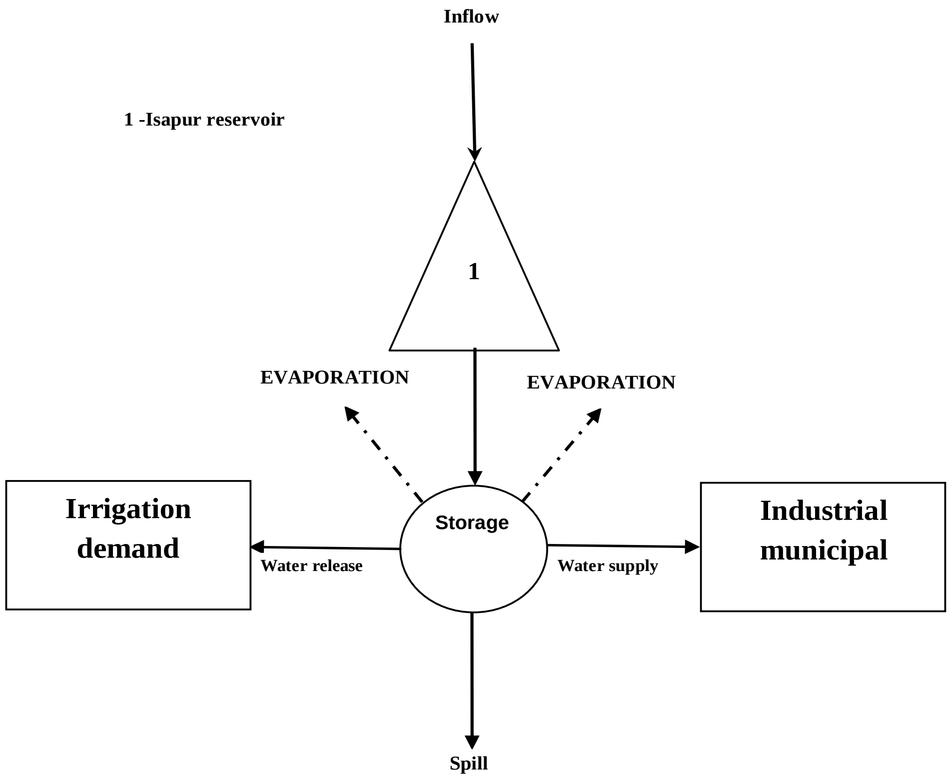

Figure 2. System model**.**

Table 1. Silent features of Upper Penganga project- Isapur reservoir.

Scope of scheme	**Irrigation purpose**
Location	Penganga river at Isapur
Catchment area	4636 Km^2
Mean annual inflow (1982 to 2009)	670.98 MCM
Gross storage capacity	1241.43 MCM
Capacity of live storage	958.43 MCM
Capacity of dead storage	283.00 MCM

958.43 MCM and gross storage capacity of reservoir is 1241.43 MCM. The monthly flow data of 28-years (1982 to 2009) for Upper Penganga reservoir- Isapur Dam is considered for analysis and model is represented in Figure 2. Table 1 is the silent features of Upper Penganga Project- Isapur reservoir.

The system considered for assessment of yield by using full optimization model is Upper Penganga Project Isapur Dam. It has maximum Capacity 1241.43 MCM and minimum capacity 283 MCM. 28 years historic inflow data for the system considered is available as shown in Figure 3, 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.

Irrigation parameters (K_t) of 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. The K_t values are given in Table 2 and shown in Figure 4.

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 rate El^r is obtained by taking the product of the slope of the area elevation curve linearized above dead storage (Figure 1) 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

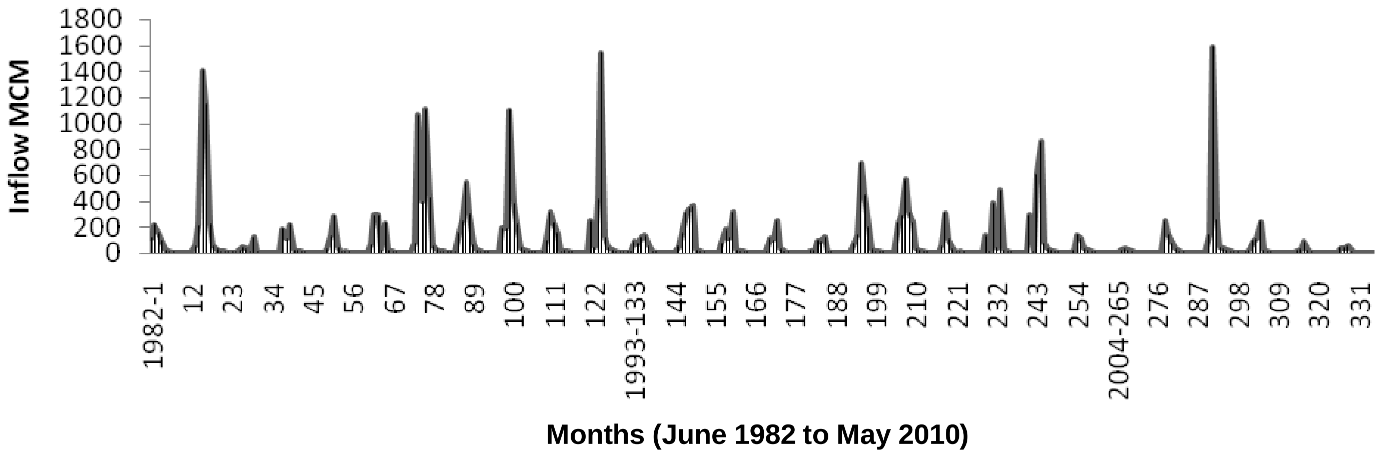

Figure 3. Penganga river Inflow at Isapur reservoir.

respective reservoirs. The values of the γ_t are given in Table 2 and shown in Figure 5.

ANALYSIS AND RESULTS

In the deterministic LP model, the study of continuous LP model – full optimization model is done. In the deterministic LP model the evaporation losses are considered. In this deterministic LP model the necessary data is shown in Table 1. For Live reservoir capacity of 958.43 MCM, yield is found out for this model. The reservoir DCLP model problem solution solved by the LINDO package tool.

In the continuous LP model or full optimization model, the monthly flow data of the all 28 years is used. This model is discussed in Equation 1 to 7. The annual yield obtained from this monthly flow model is 368.90 MCM and within-year yield is calculated and presented in the Table 3.

The simulation method is complicated in case of designing the reservoir system but in case of the operation of the reservoir it is simple. The data used for this study is the historical monthly flow data for 28 years of the Isapur reservoir. It is major irrigation reservoir with live capacity of 958.43 MCM. And for this given capacity the yield is determined. The evaporation losses and variable demand is considered in this model.

The simulation model developed uses the continuity equation for generating the reservoir operation table

[Initial storage] + [Inflow] – [Evaporation loss] – [Release] – [Spill] = [Final Storage] (8)

The results obtained for safe reservoir annual yield is 362.54 MCM and within-year yield as shown in Table 3. The simulation model developed in this study can serve as an effective tool for operation of the reservoir, for effective decision making to meet the irrigation, industrial and municipal demand. By using simulation surplus condition can be avoided by controlling the releases.

The safe reservoir yield releases obtained from the full optimization model for the months were compared with the safe reservoir yield obtained from the simulation model, which show an accurately close trend for months as shown in the Figure 6. The annual water release targets with safe reservoir yield obtained by full optimization model is 368.90 MCM and simulation model is 362.54 MCM. The difference in the annual targets in both models is only 6.36 MCM. So the accuracy of full optimization model results are accurately matching with the simulation targets. This finding reinforces the appropriateness of the application of full optimization model analysis.

Conclusion

The Deterministic LP models are simple to use for determination of reservoir capacity for a given yield or determination of safe/ firm yield for a given demand. Full optimization model contains all the within-year periods of data and so give the accurate reservoir capacity or storage capacity. The main limitation of deterministic full optimization model is considering the monthly flow and monthly evaporation so that the size of the model is increased. The actual safe reservoir yield of Isapur reservoir as per the Water resource department is 370.65 MCM and optimum value of Full optimization model is 368.90 MCM so it nearly accurate the results. The process of simulation is tedious but is likely to produce more accurate results due to a close representation of the actual system. In the simulation model, evaporation losses calculation is more specific than the Deterministic LP model and so the yield obtained from the simulation model is more accurate, when comparison of annual targets by full optimization model with simulation, safe reservoir yield demand was satisfied perfectly.

The choice of method of analysis and model shall

Table 2. within –year inflow approximation, Irrigation and evaporation parameters used in the full optimization model for Isapur reservoir in Penganga river in Godavari Basin.

Parameter		Parameter	Within-year time period (Months)					
E0	**E1^r**		**June**	**July**	**August**	**September**	**October**	**November**
		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
		Avg. Inflow MCM	51.85	108.13	228.01	187.68	71.99	11.53
64.67	0.117	**Parameter**	**December**	**January**	**February**	**March**	**April**	**May**
		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
		Avg. Inflow MCM	5.57	2.46	1.36	0.84	0.71	0.84

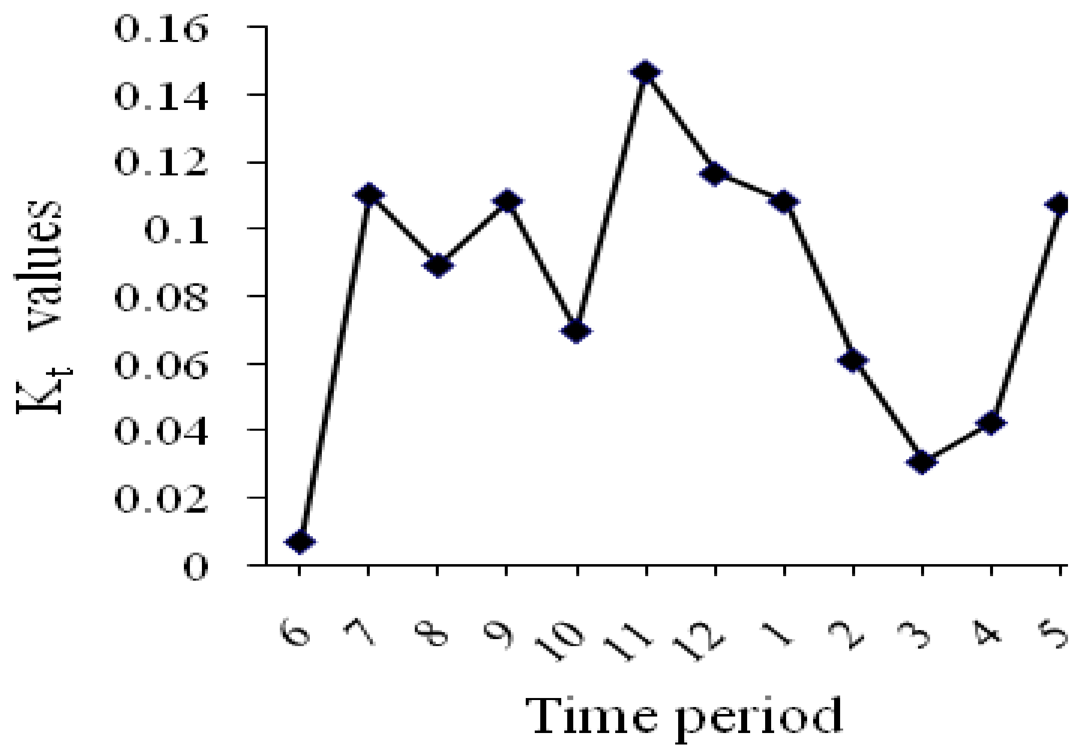

Figure 4. Values ok K_t for UPP Isapur reservoir.

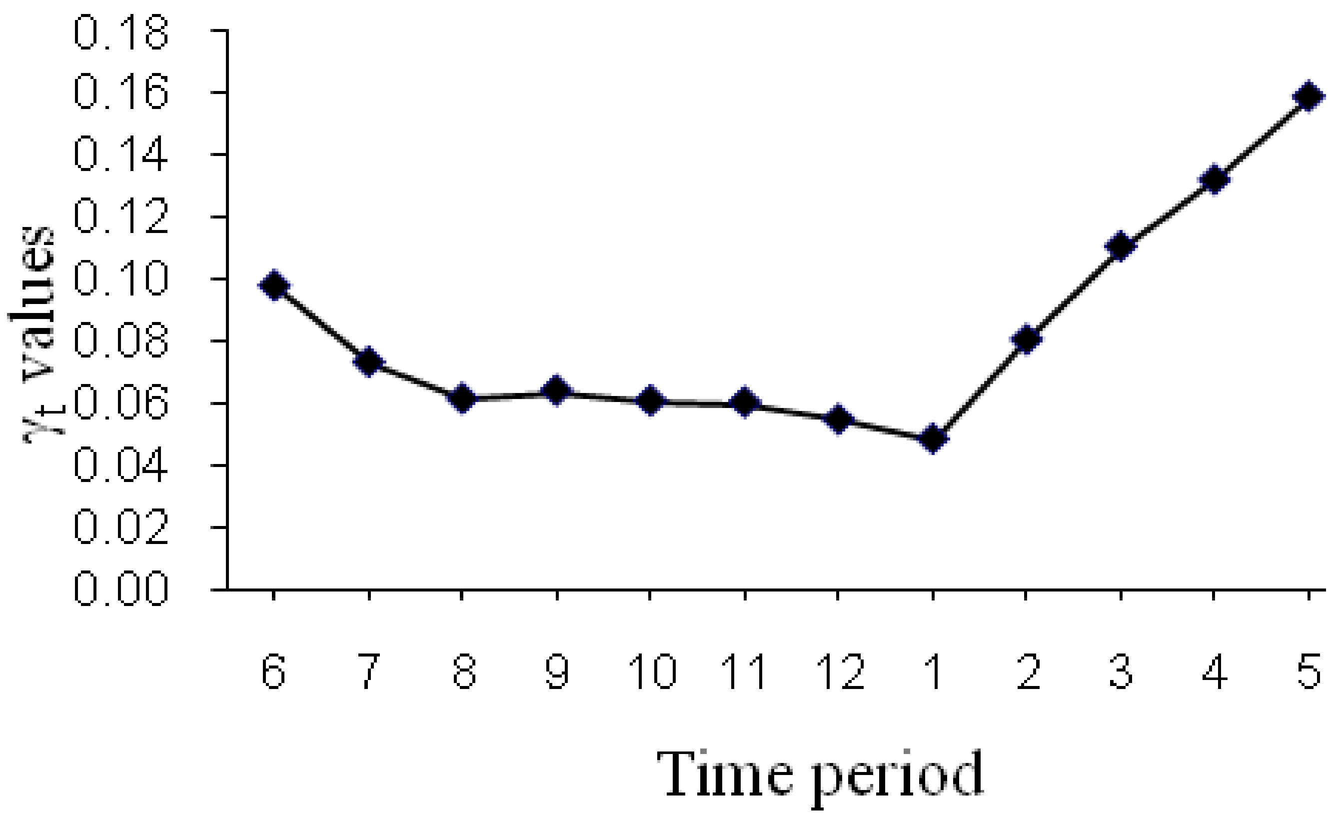

Figure 5. Values of Y_t for UPP Isapur reservoir.

Table 3. Representing the monthly firm water releases for irrigation, industrial and municipal.

Yield (MCM)	Within-year time period					
	June	**July**	**August**	**September**	**October**	**November**
Safe reservoir yield (full optimization model)	2.78	40.67	32.99	40.04	25.82	54.07
Safe reservoir yield (simulation model)	2.75	39.98	32.41	39.33	25.38	53.14
	December	**January**	**February**	**March**	**April**	**May**
	42.97	39.93	22.60	11.50	15.78	39.7
	42.23	39.26	22.22	11.31	15.51	39.01

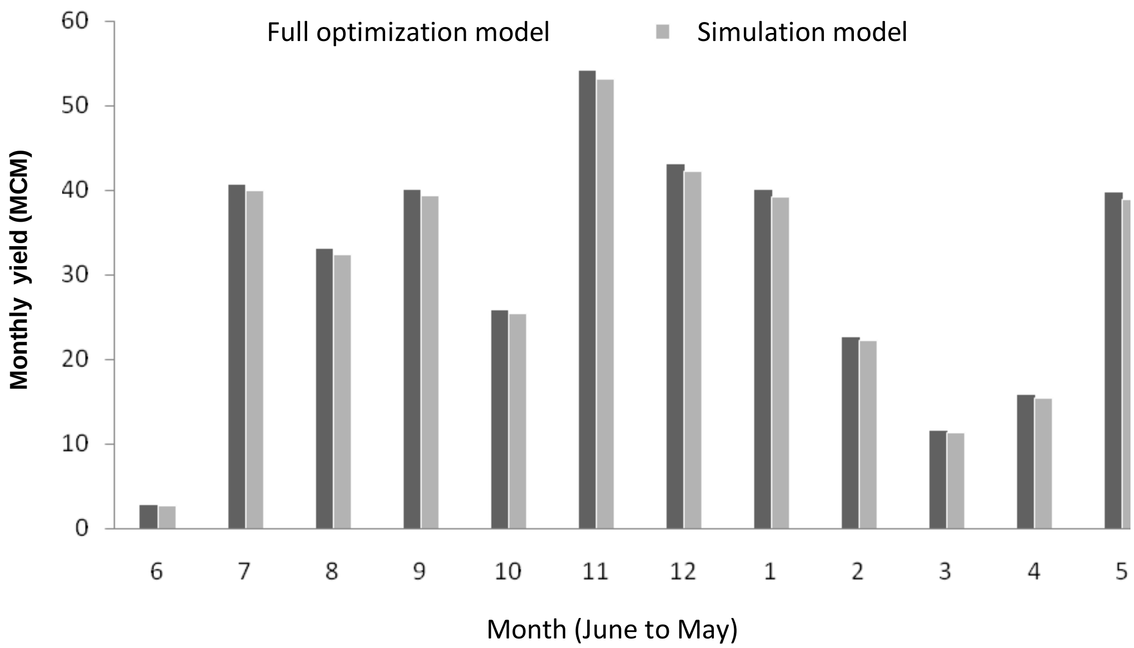

Figure 6. Comparison of full optimization model and simulation model.

depend upon factors like the nature of study, its purpose and the size of problem. The simulation model improves results of optimization model. Therefore using of simulation model is necessary after optimization.

REFERENCES

Chaturvedi MC, Srivastava DK (1981). "Study of a complex water resource system with screening and simulation models." Water Resour. Res., 17(4): 783-794.

Dandy GC, Connarty MC, Loucks DP (1997). "Comparison of Methods for Yield Assessment of Multipurpose Reservoir Systems." ASCE, J. WRPM, 123(6): 350-358.

Hall WA, Dracup JA (1970). Water Resources System Engineering. McGraw Hill Inc., New York, U.S.A., pp. 222-231.

Loucks DP, Sigvaldason OT (1982). Multiple-reservoir operation in North America, *in* The Operation of Multiple Reservoir systems, edited by Z. Kaczmareck and J. Kindler, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 147-155.

Loucks DP, Stendiger JR, Haith DA (1981). Water resource systems planning and analysis. Prentice-Hall, Inc., Englewood Cliffs, N. J., pp. 339-353, 368-371.

Simonovic SP (1992). "Reservoir system analysis: Closing gap between theory and practice." J. Water Resour. Plann. Manage. ASCE, 118(3): 262-280.

Wurbs RA (1993). "Reservoir management and operation models." J. Water Resour. Plann. Manage. ASCE, 119(4): 455-472.

Yeh WWG (1985)."Reservoir Management and Operations Models: A State-of-the-Art Review." Water Resour. Res., 21(12): 1797-1818.