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An Improved Multireservoir Multiyield Preliminary Screening Model

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Abstract: *Yield model serves as an efficient preliminary screening model for reasonable reservoir designs with release reliabilities near targets. This paper extends the yield model as available in the present form and presents an improved general-purpose yield model to apply to a multiple reservoirs system consisting of single purpose and multipurpose reservoirs. The model is capable of considering more number of water uses, different reliabilities for each water use, allows deficit in annual yields during failure years, and redistribution of regenerated flows in within year periods. The model can be applied to both compatible and incompatible water purposes, and considers each purpose independently or in-group, depending on total number of purposes to be considered in a reservoir. The model is compared with two existing yield models and it is found that the model offers better flexibility in selecting reliabilities and deciding optimal yield failures during failure years for different water uses.*

Key words: Reservoirs; Yield model; Reliability; Linear programming.

Introduction

The concept of yield model was introduced by Loucks et al. (1981). Yield model is an implicit stochastic screening model, which separately considers over year and within year capacity requirements to meet the specific release reliability targets based on the historical flow records. Over year capacity is governed by the distribution of annual stream flows 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 within the 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 capacity is simply the sum of over year storage and within year storage capacities. The model considers yearly flows for over year storage requirement. The within year storage is determined through the critical year. As it is not possible to identify the critical year at the time of model development, it is assumed that reservoir inflow at within year time t is β_t times the total annual yield of reservoir, where β_t is the ratio of inflow in period t of the driest year of record to the total inflow that year.

Simple optimization models can be useful for identifying potentially attractive reservoir system configurations and capacities in early stages of system design. Several families of such screening models have been developed. Their ability to identify cost-effective designs that meet specified draft reliability targets was evaluated by Stedinger et al. (1983) by simulating different designs identified as potentially optimal by the various models and observed that chance constrained models, though simple, generally performed poorly, the yield model performed quite well. Dandy et al. (1997) compared four different methods for estimating the yield of a multiple reservoir system. The methods include simulation, a combined simulation-optimization model (WATHNET), a full optimization model and the yield model. The four methods were used to estimate safe historical yield of the Canberra water supply system (Australia). It was found that full optimization model and yield model provide high estimates of the system yield because they assume perfect knowledge of future inflows. WATHNET presents a reasonable compromise in estimating the system yield using implied operating rules that are achievable in practice. The concept of the original LP based yield model is employed through a combination of simulation and nonlinear optimization techniques for multipurpose multireservoir systems (Lall and Miller, 1988, Lall, 1995, Sinha et al., 1999). Dahe (2001) and Dahe and Srivastava (2002) extended the yield model to apply for a multiple reservoirs system that consists of a combination of single purpose and multipurpose reservoirs, and illustrated the model by applying it to a system of eight reservoirs in the upper basin of the Narmada river in India. The objective is to achieve prespecified reliabilities for irrigation and energy generation and to incorporate an allowable deficit in the annual irrigation target. The authors explained how a single yield problem could be converted to a multiple yield problem that represents the same irrigation deficit criterion while maintaining the desired reliability. The model considers two yields, one firm with maximum possible reliability, and the other, secondary.

The model presented in Dahe and Srivastava (2002) is the last available form of yield model using linear programming. The model served its intended purpose for application in the upper basin of the Narmada river, but it is felt that it cannot be applied for all the basins. This paragraph discusses the difficulties with the yield model in Dahe and Srivastava (2002) for application in general purpose. (i) It is not always necessary that the reliability of one reservoir yield for a specific water purpose should always be the maximum possible, given by n/(n+1) in a sample size of n. In actual practice, some deficit in annual yields for some water purposes may be permitted. For example, in India, the target reliabilities for hydropower generation and irrigation are 90% and 75%, respectively. In the model application presented in Dahe and Srivastava (2002), as the considered reliability is higher than target reliability for one purpose (hydropower), the estimated reservoir capacity will also be higher to meet known hydropower demand, or estimated hydropower release will be less for known reservoir capacity. (ii) The value of failure fraction, which defines the proportion of the annual secondary reservoir yield to be made available during failure years, is either one for successful years, or zero, for failure years. Failure fractions cannot be greater than zero during failure years, as the firm yield is essentially increased by an amount equal to failure fraction times the secondary yield. The water purposes considered in Dahe and Srivastava (2002) are irrigation and hydropower generation, which are compatible, i.e., water put to irrigation use can also generate power. In cases, where the purposes are incompatible, e.g., irrigation and water export to other reservoirs; one purpose will not be served at all during failure years, as the failure fraction is zero for failure years. The failure of a purpose completely (zero yield) for a whole year may not be accepted at all. (iii) Regulation of upstream reservoirs when affect a reservoir, the model does not allow redistribution of regenerated flows from upstream water uses. It is assumed that the regenerated flows for a particular yield from upstream use at a within year time will simply pass through the reservoir and add to the particular yield (firm or secondary) of the reservoir at that time. When regenerated flows are very high from water uses of upstream reservoirs for a particular yield, at a within year time, it may be even greater than the demand for the particular yield at that time for the concerned downstream reservoir. (iv) The fractions of annual irrigation target and firm energy target in a period are different. During secondary yield failure years, the within year firm yields may not satisfy both the fractions, and the model may not give feasible results.

Priority Yield and Second Yield

Two new terms priority yield and second yield are introduced in this paper, and they may not be same as firm yield and secondary yield, respectively. The firm yield is that yield, which the reservoir will always be able to provide and that larger yields are not firm in the sense that they cannot be always met. In probabilistic terms, the firm yield has the maximum possible reliability, i.e., no failure years, and is given by n/(n+1), in an n year record by using the Weibull plotting position formula. All yields in addition to the firm yield having reliability less than the firm yields are secondary yields. The terms priority yield and second yield are used for the yields that have no restriction on reliability in the possible range of reliabilities 1/(n+1) to n/(n+1). Here, the planner can prefix or calculate from model results the reliabilities of both the yields. The two yields or one yield may be used partially or fully for a definite water purpose or purposes.

Model Development

The yield model as available in the present form is improved and extended to have more freedom of application and to include more number of water needs, both compatible and incompatible. The variables are named in the same pattern and style as given in Dahe and Srivastava (2002). Let indexes i, j and t refer to a reservoir site, to a year, and to a within year period, respectively; and k refers to a reservoir amongst the set of m contributing reservoirs upstream of the reservoir i. Let $Oy_i^{P,p1}$ is annual priority yield of reservoir i with reliability p1; $Oy_i^{S,p2}$ is annual second yield of reservoir i with reliability p2; $Oy_{P,p1}^{i,t}$ and $Oy_{S,p2}^{i,t}$ are priority and second yields, respectively for reservoir i at within year time t; $I_{i,j}$ is inflow to reservoir i in year j; $\mathrm{Im}_{i,j}^{k}$ is import to reservoir i in year j from reservoir k; $S_{i,j}^{0}$ is over year storage of reservoir i in year j; $S_{i,t}^{w}$ is within year storage of reservoir i in period t; Y_i^0 and Ya_i are over year storage capacity and total active storage capacity, respectively for reservoir i; $El_{i,j}$ is evaporation from reservoir i in year j; $El^{i,t}$ is evaporation from reservoir i at time t; $Sp_{i,j}$ is annual spill from reservoir i in year j; $Sp_{k,j}$ is spill from upstream reservoir k in year j; δ_k^P and δ_k^S are fractions of priority yield, $\sum_t (Oy_{P,p1}^{k,t})$, and second yield, $\sum_t (Oy_{S,p2}^{k,t})$, respectively coming as regenerated flow from water uses of upstream reservoir k; $\theta_{p1,j}$ is failure fraction of priority yield with reliability p1, to be made available during failure years; and, $\theta_{p2,j}$ is failure fraction of second yield with reliability p2, to be made available during failure years. To allow redistribution of water imports from upper reservoir k and regenerated flows from upstream water uses, the annual water imports and regenerated flows are added to reservoir inflows in the over year storage continuity equation.

The over year storage continuity equation can be written as

$$\begin{aligned} & S_{i,j-1}^{0} + \sum_{k\varepsilon m}\left(Sp_{k,j}\right) + I_{i,j} + \mathrm{Im}_{i,j}^{k} + \sum_{k\varepsilon m}\left\{\delta_k^P \sum_t \left(Oy_{P,p1}^{k,t}\right) + \delta_k^S \sum_t \left(Oy_{S,p2}^{k,t}\right)\right\} \qquad \forall i,j \qquad (1) \\ & -\theta_{p1,j} Oy_i^{P,p1} - \theta_{p2,j} Oy_i^{S,p2} - El_{i,j} - Sp_{i,j} = S_{i,j}^{0} \end{aligned}$$

where $\theta_{p1,j}, \theta_{p2,j} \le 1$ for failure years, and
=1 for successful years.

Here, both priority and second yields can fail during failure years, and both failure fractions, $\theta_{p1,j}$ and $\theta_{p2,j}$, may be greater than zero during failure years. The firm yield of the reservoir is $\left(\theta_{p1,j} Oy_i^{P,p1} + \theta_{p2,j} Oy_i^{S,p2}\right)$ and the secondary yield is $\left\{Oy_i^{P,p1}(1-\theta_{p1,j}) + Oy_i^{S,p2}(1-\theta_{p2,j})\right\}$. The annual reliability of priority yield and second yield can be same or different, for each reservoir. The failure fractions, $\theta_{p1,j}$ and $\theta_{p2,j}$ need not be same for all the reservoirs. If a reservoir has four incompatible water purposes to serve, say, X1, X2, X3 and X4, where X1 and X2 require maximum possible annual reliability (no failure years). Then X1 and X3 may be considered as priority yield, and X2 and X4 may be considered as second yield. The values $\theta_{p1,j}$ and $\theta_{p2,j}$ should be so selected that, $\theta_{p1,j} Oy_i^{P,p1}$ value is more than or equal to the firm water requirement for X1 and $\theta_{p2,j} Oy_i^{S,p2}$ value is more than or equal to the firm water requirement for X2. Of course, here X3 will completely fail (zero yield) during failure years if $\theta_{p1,j} Oy_i^{P,p1}$ is equal to the firm water requirement for X1, and X4 will completely fail during failure years if $\theta_{p2,j} Oy_i^{S,p2}$ is equal to the firm water requirement for X2. But this problem was already there, when yield model could be applied for two incompatible purposes. If a reservoir has two water purposes, than both the purposes can be served partially during failure years. If a reservoir has two distinct purposes, one firm and one secondary (say, domestic water supply and irrigation, respectively), then $\theta_{p1,j}$ can be made one (1) for all the years to serve the firm demand.

The basic assumption in the yield model is that the total inflow in the critical year is equal to the total yearly yield, so that the reservoir neither fills nor empties during the modeled critical year (Loucks et al. 1981). In within the year storage continuity equation, $\beta_{i,t}$ times the annual import and regenerated flow is subtracted from reservoir inflow; and import and regenerated flow at time t is added to reservoir inflow.

$$S_{i,t-1}^{w} + \beta_{i,t}\left[Oy_i^{P,p1} + Oy_i^{S,p2} + \sum_t El^{i,t} - \sum_{k\varepsilon m}\left\{ \delta_k^P \sum_t \left(Oy_{P,p1}^{k,t} \right) + \delta_k^S \sum_t \left(Oy_{S,p2}^{k,t} \right) + \mathrm{Im}_{i,j}^{k} \right\} \right]$$
$$+ \sum_{k\varepsilon m} \left\{ \delta_k^P \left(Oy_{P,p1}^{k,t} \right) + \delta_k^S \left(Oy_{S,p2}^{k,t} \right) + \mathrm{Im}_k^{i,t} \right\} - \left(Oy_{P,p1}^{i,t} + Oy_{S,p2}^{i,t} + El^{i,t} \right) = S_{i,t}^{w} \quad \forall i,t \qquad (2)$$

If all the within year storage continuity equations for a reservoir are added, the total assumed yearly inflow is equal to the total yearly yields including evaporation. So, the basic assumption regarding critical years inflow in Loucks et al. (1981) is not violated and at the same time the model allows redistribution of regenerated flows in within year time periods.

As regenerated flows are redistributed, the continuity of annual yields at each reservoir site, may be written as

For priority yield,

$$\sum_t Oy_{P,p1}^{i,t} = Oy_i^{P,p1} \qquad \forall i,t \qquad (3)$$

For second yield,

$$\sum_t Oy_{S,p2}^{i,t} = Oy_i^{S,p2} \qquad \forall i,t \qquad (4)$$

The release target constraints for priority and second yields, as per within year requirements,

$$Oy_{P,p1}^{i,t} = K_{i,t}^{P}\left(Oy_i^{P,p1} \right) \qquad \forall i,t \qquad (5)$$

$$Oy_{S,p2}^{i,t} = K_{i,t}^{S}\left(Oy_i^{S,p2} \right) \qquad \forall i,t \qquad (6)$$

However, for a single purpose reservoir, a common release target is adopted.

$$Oy_{P,p1}^{i,t} + Oy_{S,p2}^{i,t} = K_{i,t}\left(Oy_i^{P,p1} + Oy_i^{S,p2} \right) \qquad \forall i,t \qquad (7)$$

where $K_{i,t}^{P}$, $K_{i,t}^{S}$ and $K_{i,t}$ are proportions of annual priority, second and total yields, respectively for reservoir i.

If the objective of the model is to maximize total yield, i.e., $\left(Oy_i^{P,p1} + Oy_i^{S,p2}\right)$, it may tend to maximize the yield, which has less reliability and less failure fraction, at the cost of the other yield, which may not be desirable. In order to have a relationship between priority yield and second yield, a relation constraint is added.

$Oy_i^{P,p1} = \alpha_i Oy_i^{S,p2} \quad \forall i \in$ reservoirs where both priority and second yields are unknown. (8)

where α_i is the desired ratio of priority yield to second yield for reservoir i. Equation (8) is not required if any of the yield values, priority or second, is already known.

The over year active storage volume capacity constraint, total active storage capacity constraint and definition of estimated evaporation losses presented in Loucks et al. (1981) and Dahe and Srivastava (2002) are not changed.

Over year active storage volume capacity for year j at reservoir i,

$$S^0_{i,j-1} \le Y^0_i \qquad \forall i, j \qquad (9)$$

Total active storage capacity for reservoir i,

$$Y^0_i + S^w_{i,t-1} \le Ya_i \qquad \forall i, t \qquad (10)$$

Definition of estimated evaporation losses in year j for reservoir i,

$$El_{i,j} = EO_i + \left[S^0_{i,j-1} + \sum_t \left(\frac{S^w_{i,t-1} + S^w_{i,t}}{2} \right) \gamma_{i,t} \right] El^a_i \qquad \forall i, j, t \qquad (11)$$

where EO_i is average annual fixed evaporation volume loss from dead storage for reservoir i, El^a_i is average annual evaporation volume loss rate per unit of active storage volume for reservoir i, and $\gamma_{i,t}$ is fraction of annual evaporation volume loss from reservoir i in period t.

Definition of estimated evaporation losses in time t (assuming that the initial over year storage volume $S^0_{i,cr}$ in the critical year is zero) for reservoir i,

$$El^{i,t} = \gamma_{i,t} EO_i + \left(S^0_{i,cr} + \frac{S^w_{i,t-1} + S^w_{i,t}}{2} \right) \gamma_{i,t} El^a_i \qquad \forall i, t \qquad (12)$$

If a reservoir has two compatible purposes, say, irrigation and power generation, where irrigation water is also available for power generation, firm yield and secondary yields are required for firm and secondary energy calculations. The following constraints are added.

Firm water yield of reservoir i,

$$OFy^t_i = \theta_{p1,j} Oy^{i,t}_{P,p1} + \theta_{p2,j} Oy^{i,t}_{S,p2} \qquad \forall i, t \qquad (13)$$

Secondary water yield of the reservoir i,

$$OSy^t_i = \left(1 - \theta_{p1,j}\right) Oy^{i,t}_{P,p1} + \left(1 - \theta_{p2,j}\right) Oy^{i,t}_{S,p2} \qquad \forall i, t \qquad (14)$$

Continuity of firm yield,

$$OFy_i = \sum_t OFy_i^t \qquad \forall i,t \qquad (15)$$

Continuity of secondary yield,

$$OSy_i = \sum_t OSy_i^t \qquad \forall i,t \qquad (16)$$

To allow distribution of firm energy as per time wise requirement $(\eta_{i,t})$, the volume of water required to generate firm energy at time t may not be same as firm water yield available at that time. The part of the firm water yield at time t, $OFEy_i^t$, which is actually used for firm power generation, is made less than equal to the firm water yield at time t.

$$OFEy_i^t \le OFy_i^t \qquad \forall i,t \qquad (17)$$

The part of the firm water yield, which is not used for firm energy generation, is added to the secondary water yield for secondary power generation. As reliability of firm yield is higher than reliability of secondary yield, it can be added to secondary yield without any change in reliability of secondary yield.

$$OSEy_i^t \le OSy_i^t + \left(OFy_i^t - OFEy_i^t\right) \qquad \forall i,t \qquad (18)$$

$OSEy_i^t$, the part of the secondary water yield which is used for secondary energy generation at time t, is made less than or equal to the secondary yield available for power generation, to allow the plant capacity limitation constraint to play its part.

Firm energy generation,

$$E_{i,t} = \left(CF.e_i.Ha_{i,t}\right)OFEy_i^t \qquad \forall i,t \qquad (19)$$

Secondary energy generation,

$$\overline{E}_{i,t} = \left(CF.e_i.Ha_{i,t}\right)OSEy_i^t \qquad \forall i,t \qquad (20)$$

Plant capacity limitation,

$$E_{i,t} + \overline{E}_{i,t} \le \left(\alpha_{i,t} h_{i,t} H_i\right) \qquad \forall i,t \qquad (21)$$

Firm energy target constraint,

$$E_{i,t} = \eta_{i,t} E_i \qquad \forall i,t \qquad (22)$$

Annual secondary energy generation,

$$\sum_t \overline{E}_{i,t} = \overline{E}_i \qquad \forall i,t \qquad (23)$$

where CF = conversion factor for computation of hydro-electric energy, $e_i =$ hydropower plant efficiency for reservoir i, $E_{i,t} =$ firm energy generation for reservoir i in time t, $\overline{E}_{i,t} =$ secondary energy generation for reservoir i in time t, $E_i =$ annual firm energy generation for reservoir i, $\overline{E}_i =$ annual secondary energy generation for reservoir i, $H_i =$ hydropower plant capacity for reservoir i, $Ha_{i,t} =$ productive storage head for reservoir i in period t, $h_{i,t} =$ number of hours for generation of energy for reservoir i in period t, $\alpha_{i,t} =$hydropower plant factor for reservoir i in period t, and $\eta_{i,t} =$percentage fraction of annual firm energy target for reservoir i in period t

The equations (1) through (23) define the improved general-purpose yield model (IGPYM), which can be applied to a system of reservoirs having compatible, incompatible, single and multi uses. The objective function may be to maximize yields, or return from yields, or to minimize reservoir capacity.

Comparison of the IGPYM with previous yield models

The IGPYM uses two failure fractions, instead of one, used in Loucks et al. (1981), Stendinger et al. (1983), Dandy et al. (1997), and Dahe and Srivastava (2002). Apart from allowing both the yields to have desired reliabilities, how these failure fractions affect the required reservoir capacity or the annual yields, is shown by comparing the models given in Loucks et al. (1981), Dahe and Srivastava (2002) and the model presented in this paper. For comparing, a nine-year, two season stream flow data given in Loucks et al. (1981) is used, neglecting evaporation losses. The flows are 1.0, 3.0, 0.5, 2.5, 1.0, 2.0, 0.5, 1.5, 0.5, 0.5, 0.5, 2.5, 1.0, 5.0, 2.5, 5.5, 1.5, and 4.5. The β_t values are taken as 0.5 for both the periods. The values for the factor K_t are assumed to be 0.6 for the first period and 0.4 for the second period. Three cases are formulated for these data as follows-

Case-1: Loucks et al. (1981) model

To determine the maximum annual reservoir yield with 70% reliability and 20% allowable deficit, for a known reservoir capacity of 2.5, a single yield model is formulated. The fourth and fifth years are taken as failure years. A failure fraction value equal to 0.8 is used to the annual reservoir yield during failure years to satisfy the allowable deficit criterion. The model is solved and the value of annual total reservoir yield is found to be 3.09.

Case-2: Dahe and Srivastava (2002) model

A multiple yield model is formulated by incorporating two annual reservoir yields, one firm, i.e. with maximum possible reliability (90%) with the given set of data and the other, secondary, with 70% reliability (2 failure years). The fourth and fifth years are taken as failure years for secondary yield. The value of failure fraction in the constraint for the allowable annual deficit criterion is taken as 0.8, to maintain the proportion of annual reservoir yields during successful and failure years as that of the single yield problem of case1. The objective in this case is to determine the minimum capacity of a reservoir, to obtain an annual reservoir yield of 3.09 (sum of firm and secondary yields). The solution of this model gives results identical to case 1 with a reservoir capacity of

2.5. The values of annual yields obtained are, firm yield=2.47 and secondary yield=0.62.

Case-3: The improved general-purpose yield model
It is assumed that the reliabilities of priority and second yields are 80% (one failure year) and 70% (two failure years), respectively. The fifth year is taken as failure year for the priority yield and the fourth and fifth years are taken as failure years for second yield. It is also decided that 50% of the priority yield would be supplied during priority yield failure year and 20% of second yield would be supplied during second yield failure years. That means, both priority and second yields will not fail totally. The value of α_i in the relation constraint is made equal to four (4) to make the ratio of priority yield and second yield equal to as that of firm yield and secondary yield in case-2. The constraints for proportioning of yields (release target constraint) are kept same as case-2 to have better comparison. The solution of the model for an objective function to determine the minimum capacity of the reservoir, to obtain an annual reservoir yield of 3.09 (sum of priority and second yields) gives identical values for priority yield and second yield as that of firm and secondary yields in case 2. But the required reservoir capacity is reduced from 2.5 to 1.5. The firm yield in case-1 and case-2 is 2.47. But in the present case the firm yield is reduced from 2.47 to 1.36 (0.5 X 2.47 + 0.2 X 0.62). The solution of the model for an objective function to maximize the total yields for a reservoir capacity of 2.5 gives the values of priority yield and second yield equal to 2.65 and 0.66, respectively, i.e., a total yield of 3.31 against 3.09 in Case-1 and Case-2. The firm yield in this case is 1.46 (0.5 X 2.65+ 0.2 X 0.66), and secondary yield is 1.85 (3.31-1.46). Thus the IGPYM offers better flexibility in selecting reliabilities of water uses and deciding optimal yield failure fractions during failure years for different water uses. That is, at a given reservoir, if the desired reliabilities of both the priority and second yields are less than the maximum possible reliability given by n/(n+1), with or without complete yield failure for any yield (priority or second) during failure years, the system represented by the IGPYM is capable of supplying the same annual yields with desired reliabilities from reduced reservoir capacity, or higher annual yields with the given reservoir capacity. The model can act as a better screening tool in planning by providing outputs that can be very useful in improving the efficiency and accuracy of models such as dynamic programming and detailed simulation.

Conclusion

The objective of the work is to present a realistic and efficient yield model for screening purpose, related to multi site, multipurpose reservoir systems. The focus is on dealing the reservoir purposes individually as much as possible, both for compatible and incompatible uses. An attempt is made to allow regenerated flows to redistribute in within the year period in the present model. Though the model considered priority yield and second yield, firm and secondary yields can also be calculated, and used whenever required. Previous yield models did not permit yield failure for both the yields, and yield was zero for secondary yield during failure years. The presented model permits complete or partial yield failure for both the yields. The use of priority yield and second yield allows selecting the number of failure years for each yield. Thus yields corresponding to different reliabilities, for each water need can be estimated by changing the number of failure years for that yield. The incorporation of yield relation constraint (equation 11) helps in finding the trade-off between priority yield and second yield for each reservoir in the system. The use of separate failure fractions for both priority and second yield helps in monitoring the allowable deficits in annual targets of water uses. The presented model is an improvement over the previous yield models and can be applied to any multi site multipurpose reservoirs system. It can act as a better screening tool in planning by providing outputs that can be very useful in improving the efficiency and accuracy of detailed analysis methods such as dynamic programming and simulation.

Reference

Dahe, P.D., and Srivastava, D.K. (2002). "Multireservoir multiyield model with allowable deficit in annual yield." *J. Water Resour. Plng. Mgmt.*, ASCE, 128 (6), 406-414.

Dandy, G.C., Connarty, M.C., and Loucks, D.P. (1997). "Comparison of methods for yield assessment of multiple reservoir systems." *J. Water Resour. Plng. Mgmt.*, ASCE, Vol. 123 (6), 350-358.

Lall, U. (1995). "Yield model for screening surface and ground water development." *J. Water Resour. Plng. Mgmt.*, ASCE, 121 (1), 9-22.

Lall, U., and Miller, C.W. (1988). "An optimization model for screening multipurpose reservoir systems." *Water Resour. Res.*, 24 (7), 953-968.

Loucks, D.P., Stedinger, J.R., and Haith, D.A. (1981). *Water Resources Systems Planning and Analysis*. Prentice-Hall. New Jersey.

Sinha, A.K., Rao, B.V., and Bischof, C.H. (1999a). "Nonlinear optimization model for screening multipurpose reservoir systems." *J. Water Resour. Plng. Mgmt.*, ASCE, 125 (4), 229-233.

Sinha, A.K., Rao, B.V., and Lall, U. (1999b). "Yield model for screening multipurpose reservoir sustems." *J. Water Resour. Plng. Mgmt.*, ASCE, 125 (6), 325-332.

Stedinger, J.R., Sule, B.F., and Pei, D. (1983), "Multiple reservoir system screening models." *Water Resour. Res.*, 19 (6), 1383-1393.