Simulation of Uda Walawe Reservoir Operation

by S. SELVALINGAM

SYNOPSIS
Uda Walawe reservoir has an active storage of about 180,000 ac. ft. Last two years experience of water management shows that the water requirement per acre is high compared to the values on which the scheme was originally planned. Optimum operating rules are thus essential especially when the whole area under the scheme is settled.

Historical data of streamflows available are too short for a satisfactory solution. Sufficient lengths of streamflow values were synthesised using data generation techniques, and the behaviour of the reservoir was studied through simulation of reservoir operation. The operating rules were based on two types of policies, namely the regressive and the standard policy.

Additional benefits resulting from the increase of reservoir storage are briefly discussed here. The optimum operation rules for this storage are also given.

1. Introduction
1.1 Satisfactory operation rules of reservoirs or system of reservoirs cannot be achieved with the aid of historical data which are comparatively shorter than the life time of the project. In the recent past methods have been developed to generate riverflow data and these methods account for the expected variation of inflow sequences to reservoirs. These generation methods fall into the category of procedures known as Stochastic Hydrology, a fast developing field. The apparent advantages of stochastic hydrology techniques are fairly well known. In this paper, these techniques have been used to simulate the operation of the Uda Walawe reservoir and to study its increased performance (if any) when the storage capacity is increased.

1.2 The purpose of simulation is to obtain operating rules which satisfy the required demands and which are convenient to use. Two such rules are discussed here. In the first type the release in a particular month depends on the previous month storage (Dyck, 1968) and in the other the release is a function of the sum of the inflow and the previous month storage (Fiering, 1961; Young, 1967). The latter is often referred to as the standard policy.

1.3 Standard policy was used by Young (1967) and Eisel (1972) to optimize the reservoir sizes and the irrigation targets. These studies were done using mean annual inflows. A method indicated here optimizes the irrigation targets for both Maha and Yala seasons using monthly flows.

1.4 Derivation of optimum operation rules for a system or cascade of reservoirs (such as those in the Mahaweli Scheme) can be a formidable task, especially when the benefits are from both irrigation and power. Experience gained from the application of operational research techniques to a single reservoir like Uda Walawe, will be of great use when dealing with the systems of multi-purpose schemes, such as the Mahaweli project.

1.5 The Walawe project consists essentially of the Uda Walawe reservoir and two main canals, the right bank and left bank canals which take water from the reservoir to the fields. The total area coming under the irrigation of Uda Walawe reservoir is 64,500 acres, 30,500 acres on the right bank canal and 34,000 acres on the left bank canal. The type of crops include paddy, sugar cane, and cotton and other subsidiary crops. Uda Walawe reservoir estimation when planned was based on a water requirement of 10 ac. ft. per acre per annum. The monthly water demands on which the design was based, is reproduced in Table I. Experience of reservoir operation in 1971 suggests that the 14,000 acres, which were cultivated, required a supply of 262,000 ac. ft., i.e. about 18 ac. ft. per acre. Looking at these figures one obvious question arises. That is, if the whole area under the scheme is settled, how far the releases from the reservoir could be stretched without jeopardising its future performance, and what remedial measures such as increasing the reservoir, etc. must be undertaken. The present paper attempts to answer, if not completely, the above posed questions.

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2. Data Generation

2.1 Two types of models are extensively used by hydrologists to generate synthetic flow sequences, viz. Markovian model and Fractional Noise model. Markovian model is essentially a short-memory process, and as such it cannot estimate accurately the long term storages. On the other hand, the Fractional Noise models fail to reproduce the short term variations. (Wallis and Matalas, 1972).

2.2 Wallis and Matalas (1972) studied the range of values of the level of demand, \( \alpha \), defined by the equation \( \sum D_j = \alpha \sum X_j \), \( D_j \), \( X_j \) are the demand and inflow respectively in a time interval \( j \), the serial correlation, \( p \), and Hurst's coefficient, \( h \), over which the design capacity of a reservoir depends on the generating mechanism of inflows. They observed that for values of \( \alpha \leq 0.80 \), the minimum design storage, determined by sequent peak algorithm depended primarily on \( p \) and that the Markovian model may be used to determine the capacity of reservoirs.

2.3 The Uda Walawe streamflow data gives an estimation of \( \alpha \), less than 82\% and \( p \), equal to 0.51. This range of values of \( \alpha \) and \( p \) justifies the use of Markovian model for the purpose of simulation. The type of Markovian model used here is the auto-regressive model of the first order.

2.4 Techniques involved in data generation procedure of the auto-regressive model has been reported elsewhere (Selvatingam, 1973), as such it would suffice if only the basic ideas are outlined here. Streamflows, in general, are composed of a trend component, periodic component, correlated component, and a random component. Standard procedures are available to detect and remove the trend and periodic components. The time series, when free of these components, is known as the 'standardised series'.

2.5 Markovian models such as the auto-regressive type express the standardised series in the form

\[
Z_t = \sum \rho_s Z_{t-s} + e_t \quad \ldots \ldots \ldots (1)
\]

where \( \rho_s \) is the serial correlation coefficient of lag \( s \),

\[ e_t \]

is the random component and termed as the "residual series". If the order of the model is one,

\[
Z_t = \rho_1 Z_{t-1} + e_t \quad \ldots \ldots \ldots (2)
\]

2.6 Accuracy of the data generation depends on the selection of the right type of distribution for the residual series. Normal and Pearson type III distributions were utilized for the residual series of the Uda Walawe streamflow data. Normal distribution was also used for the residual series of the data which was initially log-transformed. Two traces of each type were generated to make up 6 traces altogether. Experience of data generation for Kalu Ganga at Patupaula suggests that out of the six traces generated, only the ones with residual series of Pearson type III and Gaussian (after log-transformation of the initial data) are satisfactory. However the other two traces are also used for comparison purposes.

Trace 1: Pearson type III residual series, 100 years of monthly flows.
Trace 2: Pearson type III residual series, 200 years of monthly flows.
Trace 3: Normal distribution of residual series, initial data log-transformed, 100 years of monthly flows.
Trace 4: Normal distribution of residual series, initial data log-transformed, 200 years of monthly flows.
Trace 5: Normal distribution of residual series, 100 years of monthly flows.
Trace 6: Normal distribution of residual series, 200 years of monthly flows.

3. Simulation

3.1 The simulation procedure assumes the following details, viz:

(1) the monthly flow sequences, \( q_i \).
(2) the capacity of reservoir; Maximum storage \( S_m \), and dead storage, \( S_d \).
(3) the release rule, i.e. the yield function or draft policy for twelve months.

Two types of draft policies are considered here; "regressive policy" and "standard policy".

3.2 The term "regressive policy" refers to the release rule

\[
D_j = h_j (S_{j-1}, \mu) \quad \ldots \ldots \ldots (3)
\]

Note: \( i \) is the sequence index (i'th realization) and \( j \) denotes the month.

The release rule is a function of the storage of the foregoing months (Figure I (a)). The initial release rules to

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**FIG. 1(a) REgressive POLICY**
initiate the simulation procedure are obtained from the operation studies given in the ECI report (1962), which has been based on the historical data. The purpose of simulation is to obtain the stationary frequency distributions of storage, of spills, and of drafts (or release). From these the certainty of operation can be deduced.

3.3 The "standard policy" is given by,

\[ D_j = (1-a) (q_j + S_{j-1} + q_j - S) + a T \]  

(4)

where \( T \) is the target release and \( a \) is a parameter. If \( a = 1 \), the standard policy is referred to as the normal policy. Equation (4) gives the release only when \( q_j + S_{j-1} + q_j - S \) is greater than \( T \), otherwise the release is equal to \( q_j + S_{j-1} + q_j - S \), see Figure 1 (b).

\[ S_j = \begin{cases} S_e & \text{if } q_j + S_{j-1} + q_j - S \leq T, \text{reservoir empty}, \\ S_a & \text{if } q_j + S_{j-1} + q_j - S \geq T + \frac{S_m - S_e}{a}, \text{reservoir full}, \\ S_j' & \text{otherwise, reservoir normal}. \end{cases} \]

If the storage capacity \( S_m - S_e \) is divided into \( n \) intervals.

\[ S_0 < S_1 < S_2 \ldots \ldots \ldots \ldots \ldots S_n < S_a, S_a = S_e \]

then each time \( S_j \) is calculated, the count of the interval within which \( S_j \) falls is increased by 1. This procedure is repeated for \( N \) years (i.e. the length of the trace). If \( n_j \) is the count in the interval \( (S_i, S_{i+1}) \), then the probability of any storage \( S_j \) in the month \( j \), falling within this interval is \( n_j/N \). In this way the cumulative function of storage \( S_j \) can be obtained.

3.6 Frequency distribution of release.

\[ D_j \]

is the release under normal conditions of the reservoir, but when there is a deficit or excess of \( D_j \), then the possible release, \( d_j \), is given by,

\[ d_j = \begin{cases} q_j + S_{j-1} + q_j - S & \text{if } q_j + S_{j-1} + q_j - S > T, \text{reservoir empty}, \\ S_{j-1} + q_j - S & \text{if } q_j + S_{j-1} + q_j - S = T, \text{reservoir full}, \\ S_j' & \text{if } q_j + S_{j-1} + q_j - S < T, \text{reservoir normal}. \end{cases} \]

Possible releases, \( d_j \), can be divided into \( n \) intervals and cumulative frequency distribution can be found for each month.

Note: \( d_j \) is the total release from the reservoir in a particular month \( j \), it includes the evaporation and seepage losses from the reservoir.

3.7 Frequency distribution of waste.

The waste or spill occurs only when the reservoir becomes full. Therefore with the "regressive policy" the waste \( W_j \) is given by,

\[ W_j = \begin{cases} 0 & \text{if } q_j + S_{j-1} + q_j - S \leq T, \text{reservoir empty}, \\ S_j' - S_m & \text{if } q_j + S_{j-1} + q_j - S > T, \text{reservoir full}, \\ 0, S_j & \text{if } q_j + S_{j-1} + q_j - S = T, \text{reservoir normal}. \end{cases} \]

Unlike the "regressive policy" the release for the "standard policy" is a function of the inflow. Hence, there is no waste unless the canal capacity, \( Y_m \), has been exceeded.

Thus,

\[ W_j = \begin{cases} 0 & \text{if } q_j + S_{j-1} + q_j - S \leq T, \text{reservoir empty}, \\ 0, S_j & \text{if } q_j + S_{j-1} + q_j - S > T, \text{reservoir full and canal capacity not exceeded}, \\ S_j' - S_m - Y_m & \text{if } q_j + S_{j-1} + q_j - S > T, \text{reservoir full and canal capacity exceeded}, \\ 0, S_j & \text{if } q_j + S_{j-1} + q_j - S = T, \text{reservoir normal}. \end{cases} \]

Cumulative frequency distribution of waste can be obtained in the same manner as for the storage and release.
4. Optimization with "Regressive Policy"

4.1 Before the final distributions of storage, release, and waste are obtained, the release rule, \( D_q = h_j(S_{4-j} + q) \), has to be modified until the required objectives are attained. It is a kind of optimization. Optimization, not in the sense of obtaining maximum benefits from the operation but in the sense of satisfying the pre-requisite objectives. In this present study optimized rules are obtained for two different objectives.

4.2 Objective 1.

Final operation rules are such that,

1. The water level in the reservoir never drops below the minimum power pool level, 90% of the time, i.e. 90% guarantee of power production.
2. The waste is minimised. (reservoir is allowed to spill not more than 10% of the time).
3. Maximum possible yield is released in each month.

This optimum is not a very desirable one, because in certain months maximum possible releases are not necessary and reduced releases in these months would help to supply the increased demands in the other months with greater guarantee.

4.3 Objective 2.

Final operation rules should satisfy the following objectives:

1. Maximum possible releases with 85% guarantee on the firm releases for each month.
2. Minimum spill and less than ten per cent probability of the reservoir becoming empty.

4.4 Optimum seeking procedure.

As the objectives are fairly straight forward, and that there are no benefit functions involved, the optimization procedure is simply adapted from the probability theory of the balance equation, namely, \( S_k = S_{4-k} + q - D_q \).

\[
F_j^f(S) = \sum F_j(S - R) \cdot \Delta F_j(R) \quad \ldots \ldots \ldots (S)
\]

where \( F_j^f(S) \) and \( F_j(q) \) are the cumulative distribution functions of the storage and inflows in the month \( j \), respectively.

\( F_j^f(R) \) is the cumulative distribution function of \( R (= S_{4-j} - D_q) \), which can be deduced from \( F_j^f(S) \), since \( D_q \) is a function of \( S_{4-j} \).

4.5 When optimizing the release rule for the month \( j \), \( F_j^f(S) \) is known and since \( F_j(q) \) is fixed, the effect of changing the release rule may be studied through a table (format of which is given as table 2), which is based on the above equation.

### TABLE 1

Water requirements in Maha and Yala*

<table>
<thead>
<tr>
<th>Month</th>
<th>Quantity of water reqd. in ac. ft./ac.</th>
<th>50,000 ac. in Maha thou. ac. ft.</th>
<th>37,500 ac. in Yala thou. ac. ft.</th>
<th>River outlet in thou. ac. ft.</th>
<th>Total in thou. ac. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct.</td>
<td>0.00</td>
<td>0.00</td>
<td>18.8</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.80</td>
<td>25.0</td>
<td>18.0</td>
<td>43.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.80</td>
<td>25.0</td>
<td>18.0</td>
<td>43.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Jan.</td>
<td>1.50</td>
<td>75.0</td>
<td>18.0</td>
<td>93.0</td>
<td>111.0</td>
</tr>
<tr>
<td>Feb.</td>
<td>1.50</td>
<td>75.0</td>
<td>18.0</td>
<td>93.0</td>
<td>111.0</td>
</tr>
<tr>
<td>Mar.</td>
<td>0.00</td>
<td>0.00</td>
<td>18.0</td>
<td>18.0</td>
<td>36.0</td>
</tr>
<tr>
<td>Apr.</td>
<td>0.50</td>
<td>18.8</td>
<td>18.0</td>
<td>36.8</td>
<td>54.8</td>
</tr>
<tr>
<td>May.</td>
<td>1.75</td>
<td>65.6</td>
<td>18.0</td>
<td>83.6</td>
<td>101.6</td>
</tr>
<tr>
<td>Jun.</td>
<td>1.75</td>
<td>65.6</td>
<td>18.0</td>
<td>83.6</td>
<td>101.6</td>
</tr>
<tr>
<td>Jul.</td>
<td>1.25</td>
<td>46.0</td>
<td>18.0</td>
<td>64.9</td>
<td>82.9</td>
</tr>
<tr>
<td>Aug.</td>
<td>0.75</td>
<td>28.1</td>
<td>18.0</td>
<td>46.1</td>
<td>74.1</td>
</tr>
<tr>
<td>Sep.</td>
<td>0.00</td>
<td>0.00</td>
<td>18.0</td>
<td>18.0</td>
<td>36.0</td>
</tr>
</tbody>
</table>

*From ECI report (1962).
TABLE 2
For a fixed value of $S$, $R$ is given by,

<table>
<thead>
<tr>
<th>$R$</th>
<th>$S - R$</th>
<th>$\Delta F^R_j (R)$</th>
<th>$F^R_j (S - R)$</th>
<th>$F^R_j (S - R) \cdot \Delta F^R_j (R)$</th>
</tr>
</thead>
</table>

Note: $R$ can take negative values also.

4.6 Results for Objective 1.

Starting from the operation rules deduced from ECI report (1962), it was adjusted by trial and error procedure few times. Then using the equation (5) as the guide the operation rule was modified. It must be remembered that the equation (5) was used only as a guide, but it is possible to obtain analytical solution for the frequency distributions, even in the case of serially correlated inputs.

4.7 The simulation was performed on the IBM 1130 computer, Faculty of Engineering, University of Sri Lanka, Peradeniya Campus. The operation rules from the ECI report give the storage distribution as shown in figure 2. The release rules are also presented in the same figure. For instance, the storage distribution of January is such that the storage is more than 89,000 ac. ft., 95% of the time, and more than 190,000 ac. ft., 25% of the time. If the January storage is between 21,500 ac. ft. and 90,000 ac. ft. then the February release is given by the linear relation,

$$D_j = \frac{S_j - 21,500}{90,000 - 21,500} \cdot 93 \text{ thousand ac. ft.}$$

If the January storage is more than 90,000 ac. ft., then $D_j = 93 \text{ thousand ac. ft.}$

Hence the probability of February release meeting the target is equal to the probability of January storage being greater than 90,000 ac. ft., i.e. 94% from the figure. The variations of releases between the quantities marked in figure 2 are linear for all the months. For the draft policy given in figure 2, the percentages of spill for each month are high although the required demands have been met.

4.8 At this juncture it is worthwhile invoking the first set of objectives. That is to reduce the probability of spill below 10% and storage level to be higher than the minimum power pool level for more than 90% of the time. Trial and error procedure along with equation (3) required the operation rules to be modified twelve times in order to achieve the optimum rules. The result of the optimization is shown in figure 3. The result shown is for one trace only, the other traces give almost the same results.

4.9 The figure 3 indicates the maximum possible releases one can achieve without wasting water and without the reservoir level dropping below the minimum power pool elevation (table 1). But in the objective of the simulation no constraint was placed on maximum allowable releases nor on the percentage of guarantee for the firm releases. Consequence of this is that the optimized rules for Objective 1 can only be of academic interest. In spite of the fact that high releases are possible, the percentages of time the firm releases are supplied is fairly low. Also in most of the months the releases exceed the maximum canal capacity of $(600 \div 1300 = 1900$ cusec = $114,000$ ac. ft. + evaporation and seepage losses) $120,000$ ac. ft. per month. The monthly requirements in table 1 shows that in certain months (especially in April, November and December) high releases are not necessary although these may be met comparatively with high percentage of guarantee (75%). In conclusion, it may be stated that the above optimum set of rules fail to make the full use of carry over storage, both seasonal and annual, and the releases are not desirable for practical applications.

4.10 Results for Objective 2.

Having found the optimum rules for Objective 1, the optimum seeking procedure for Objective 2 is fairly straightforward. The top values of the releases for each month were reduced to $120,000$ ac. ft. per month, the maximum canal capacity of the canals. These values were then gradually reduced until the desired percentages of guarantee were obtained. The optimized result is shown in figure 4. Firm releases are met with a guarantee of more than 75% except in the months of June, July and August. Also the values of releases given in the figure include evaporation and seepage losses. The evaporation loss is on the average about $3,000$ ac. ft. per month and the seepage loss is about $1,000$ ac. ft. per month. The result of the above simulation suggested that the reservoir storage should be increased if the firm demands are to be supplied with 85% guarantee. Simulation was repeated for storages of 225 and 250 thousand ac. ft. and with the same optimum operation rules (i.e. from figure 4), and using the same six traces. The result, for the storage of 250,000 ac. ft. is shown in figure 5, the
FIG. 2 STORAGE, RELEASE AND SPILL DISTRIBUTIONS

Trace 1, Reservoir size = 192,500 ac. ft
FIG. 3 STORAGE, RELEASE AND SPILL DISTRIBUTIONS

Trace 4, Reservoir size = 192,500 ac.ft
FIG. 4  STORAGE, RELEASE AND SPILL DISTRIBUTIONS
Trace 4. Reservoir size = 192,500 ac. ft
FIG. 5. STORAGE, RELEASE AND SPILL DISTRIBUTIONS

Trace 4. Reservoir size = 250,000 ac. ft.
increase of storage to 225,000 ac. ft. did not yield the desired results. Figure 5 shows that the demands in most of the months are met with a guarantee of 85-90%, while during the months of June, July and August the firm releases can be supplied with 80% guarantee.

5. Optimization with "Standard Policy"

5.1 Past Studies

Young (1967) found that the normal operating policy was optimal for annual reservoir operation when release deficits were associated with certain piecewise linear loss functions. He used dynamic programming to optimize the irrigation targets, while Eisel (1972) used the "S method" of separable programming (Hadley, 1964) to optimize the irrigation target, standard policy and reservoir size. This was made possible because the annual outflows were assumed to be of Gaussian distribution and without any serial correlations. Langbein (1958) suggested that corrections would have to be applied to an analysis that neglected serial correlation. Burges and Linsley (1971) mentioned that correlation in runoff data played a significant part in storage estimates and that when runoff and demand were highly seasonal, monthly models were necessary for reservoir studies employing stochastically generated inflows.

5.2 Perrens and Howell (1972) studied the effects of serial correlations on reservoir behaviour and found that the time based reliability (defined as the percentage of time that a chosen release can be made, and identical with the term "percentage of guarantee" mentioned in the earlier sections) decreased with increasing serial correlations.

5.3 Optimization procedure as adopted in this study

In the present study, the reservoir size is known and it is necessary to optimize the irrigation targets for Maha and Yala seasons. Monthly water requirements within the seasons were extracted from table 1. Simulation of this design target with normal standard policy showed that failure in the Yala season occurred more than 75% of the time. Therefore if the time based reliability is used, then the entire design area (97,500 acres) cannot be cultivated in Yala season. The quantity based reliabilities (defined as the ratio of the total amount of water actually supplied to the total amount of water demanded, expressed in percentage), however, are 98.6% and 97.4%, in Maha and Yala respectively. To achieve the 90% time based guarantee the Yala cultivation area has to be reduced and this is given in table 3. The policy to be used is designated R 1. But the designed Yala cultivation will be possible, if the reservoir size is increased to 250 thousand ac. ft. (see policy R 1, table 4).

5.4 The first step in optimization procedure is thus the reduction of irrigation targets until the failure occurs only 10% of the time. The value of the parameter $a$ Equation 4 and Figure 1 (b) is then reduced to minimise the spill and at the same time making sure that the time based reliability do not go below 75% either in Maha or in Yala seasons. In addition to the above mentioned constraints, the maximum canal capacity also places a constraint on the minimum value of $a$.

Maximum value of $a = 1,$
Minimum value of $a$ is such that

$$Y_m = (1 - a) \left( S_m - S_e + Y_m \right) + a T$$

i.e.

$$a_{min} = \frac{S_m - S_e}{S_m - S_e + Y_m - T}$$

The policies with different time based reliabilities (or guarantees) for reservoir sizes of 192.5 and 250 thousand ac. ft. are given in tables 3 and 4 respectively.

5.5 The time based reliability, $p_t$, an indicator commonly used in industrial engineering, has some disadvantages when applied to Water Resources Engineering due to its dependence on the selected time interval. For example, if failure occurs in August 10 times in 100 years, then this amount to a reliability of 90% on year basis, 95% on season basis and 99.17% on monthly basis. The reliability in this case is usually taken as 95% as the failure in a month means failure in that season of the year. On the other hand, the quantity based reliability, $p_q$ is independent of the time interval.

5.6 Fahlbusch et al. (1973) found that for a particular project the relationship between $p_t$ and $p_q$ was a linear one. The values of $p_q$ calculated seasonwise are given along with the release policies in tables 3 and 4. It is evident looking at the values of $p_t$ and $p_q$ that although failure to meet the target occurs as high as 25% of the time, the actual quantity of water supplied during that season is greater than 96% of the quantity of water demanded, which is of a high reliability. The relationship between $p_t$ and $p_q$ was found to be approximately linear, and that $p_q$ decreased rapidly for Yala season than for the Maha season.

5.7 The quantity based reliability $p_q$ is perhaps more relevant when dealing with releases for irrigation, because this gives an estimate of guarantee on the basis of the amount of water deficit, which is the quantity of water the crop is expected to tolerate.

6. Summary and Conclusions

Data generated using the first order auto-regressive model has been used to simulate the performance of the Uda-Walawe reservoir. Two types of draft policies were used, one is a function of previous month storage (regressive policy) and the other a function of previous month storage and the inflow of the month in question (standard policy). Simulation with regressive draft policy was performed for two objectives. Improved performance of the reservoir, with its size increased, was also studied. The following conclusions can be derived from this study;


TABLE 3. Release rules for a Reservoir capacity of 192,500 ac. ft.

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>21.00</td>
<td>46.00</td>
<td>46.00</td>
<td>96.00</td>
<td>96.00</td>
<td>21.00</td>
<td>40.00</td>
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<td>80.00</td>
<td>67.00</td>
<td>40.00</td>
<td>21.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values of \( a \):

<table>
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<tr>
<th></th>
<th>( p_1 )</th>
<th>( p_2 )</th>
<th>( p_1 )</th>
<th>( p_2 )</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R 1</td>
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</tr>
<tr>
<td>R 2</td>
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<td>0.90</td>
<td>0.90</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>R 3</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>R 4</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>1.00</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
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<td>R 5</td>
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<td>0.85</td>
<td>0.85</td>
<td>1.00</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>R 6</td>
<td>0.85</td>
<td>0.80</td>
<td>0.80</td>
<td>1.00</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>R 7</td>
<td>0.90</td>
<td>0.90</td>
<td>0.85</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>R 8</td>
<td>0.85</td>
<td>0.80</td>
<td>0.80</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
<td>0.85</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Note:— \( p_1 \) = time based reliability.
\( p_2 \) = quantity based reliability.
TABLE 4. Release rules for a Reservoir capacity of 250,000 ac. ft.

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<td>46.00</td>
<td>96.00</td>
<td>96.00</td>
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<td>87.00</td>
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</tr>
</tbody>
</table>

Values of \( a \)

| RI    | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 95   | 99.3 | 90   | 99.2 | 60   | 60   |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|------|-------|
| RI    | 0.90 | 0.85 | 0.85 | 1.00 | 1.00 | 1.00 | 0.87 | 0.90 | 1.00 | 1.00 | 1.00 | 1.00 | 90   | 98.0 | 80   | 96.9 | 25   | 35   |
| RI    | 0.90 | 0.85 | 0.85 | 1.00 | 1.00 | 1.00 | 0.97 | 0.85 | 0.90 | 1.00 | 1.00 | 1.00 | 85   | 97.9 | 75   | 96.5 | 25   | 25   |
| RI    | 0.90 | 0.85 | 0.85 | 1.00 | 1.00 | 1.00 | 0.97 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 90   | 98.8 | 90   | 98.1 | 25   | 50   |
| RI    | 0.85 | 0.85 | 0.80 | 1.00 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 85   | 98.3 | 85   | 97.9 | 20   | 45   |
| RI    | 0.85 | 0.80 | 0.78 | 1.00 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 80   | 97.7 | 85   | 97.6 | 15   | 40   |
| RI    | 0.90 | 0.85 | 0.83 | 1.00 | 1.00 | 1.00 | 0.95 | 0.90 | 0.95 | 1.00 | 1.00 | 1.00 | 85   | 98.1 | 80   | 97.1 | 25   | 35   |
| RI    | 0.85 | 0.80 | 0.80 | 1.00 | 1.00 | 1.00 | 0.97 | 0.90 | 0.95 | 1.00 | 1.00 | 1.00 | 80   | 97.4 | 80   | 96.8 | 15   | 30   |
| RI    | 0.85 | 0.80 | 0.80 | 1.00 | 1.00 | 1.00 | 0.97 | 0.87 | 0.90 | 1.00 | 1.00 | 1.00 | 80   | 97.1 | 75   | 96.1 | 15   | 25   |

Note:— \( \hat{P}_1 \) = time based reliability.  
\( \hat{P}_2 \) = quantity based reliability.
(1) It is possible to release flows as high as 180,000 ac. ft in certain months, but with a comparatively low reliability on the firm demands.

(2) Both types of draft policies studied, suggest that it is not possible to meet the designed irrigation targets, with a time based reliability of 90%, especially in the Yala season. The optimum releases can be read off from figures 4 and 5, and from tables 3 and 4.

(3) If the designed targets are to be met with the required time based reliability, then the reservoir size must be increased to 250 thousand ac. ft. (dead storage included), i.e., corresponding to an elevation of 294 ft.

(4) Releases R 8 and R1 8 are recommended for storage sizes of 192.5 and 250 thousand ac. ft., respectively. Although these policies give time based reliabilities of 80% Maha and 80% Yala, the quantity based reliability is 97.2% Maha, 96.7% Yala for the present storage, and 97.4% Maha, 96.8% Yala for the increased storage. In addition, the rules R 8 and R1 8 minimize the spill and enable higher releases in the months of March, April, May, October, November and December. Thus, if the required demand is more water it may be released whenever possible.

(5) Quantity based reliability is perhaps a more realistic measure of the guarantee. The relationship between this and the time based reliability is approximately a linear one. Water Management policy decisions should take these facts into account.

(6) Purpose of any analysis of Water Resources Systems must be to suggest alternative to the decision maker. Bearing this in mind, few alternatives draft policies are suggested here. Advantage of simulation with synthetic data generation is that the behaviour of the system for objectives other than those mentioned here can be derived fairly rapidly. (about 5 minutes on the IBM 1130 computer)

(7) Studies of this nature are very essential before attempts are made to analyse the operation of multi-purpose reservoir systems, such as those of Mahaweli project.

References


2. Dyck, S., personal correspondence about his article “Stochastische Methoden der Speichewirtschaft”, Mitteilungen des Institutes für Wasserwirtschaft, 28, 1968.


