Real-Time Reservoir Operation for Irrigation – A Case Study

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ABSTRACT
Very few studies have been conducted to derive optimal reservoir operation policies integrating the reservoir operation with the on-farm utilisation of water by the various crops. This paper deals with the development of a model for real-time reservoir operation and also demonstrates the applicability of the model developed for a existing Chiller reservoir system in Madhya Pradesh, India.

Keywords: Real – time operation of reservoir system, Irrigation management, Linear programming, Optimization, Cropping pattern.

1 Introduction

Reservoirs are the most important components of a water resources development. Principal function of a reservoir is regulation of natural stream flow by storing surplus water in a rainy season and releasing the stored water in a future dry season to supplement the reduction in river flow. In short, the purpose of a reservoir is to equalise the natural stream flow and to change the temporal and spatial availability of water.

Real-time operation of reservoir means taking decisions regarding releases relatively quickly based on short-term information. Decisions are dependant on the storage in the reservoir and information available in the form of forecast of hydrologic and meteorological parameters. Real-time operation is especially suitable during floods where the system response changes very fast and decisions have to be taken quickly and adapted frequently. Another application of real-time operation is hydropower production. Real-Time operation is not very common in case of the reservoir systems operated for irrigation scheduling. Presently the reservoirs meant for irrigation purposes are operated on heuristics and certain rules set by experiences from the operation taken place in past. This defies the concept of water-management and much of the water in storage is lost for no reason.

In case of the reservoirs meant for irrigation, decision making at the reservoir level depends upon the water demands arising at the field level. In order to operate the reservoir in the best possible way, it becomes imperative to understand the process occurring in the crop-soil-water-atmosphere system. This helps not only in the estimation of accurate demands but also ensures optimum utilisation of water. If the processes at the field level are also modelled properly and integrated with the reservoir level model, the goal of water management can be achieved in best possible way. A major problem in Real-Time operation of reservoir systems is availability of good forecast. Usually in a reservoir system operation problems two major factors are to be forecasted, viz., the inflows to the system and the demands that have to be met. Randomness of inflows is an established fact. In the context of irrigation the demands are uncertain due to random climatic conditions. The climatic factors like evapotranspiration and rainfall are to be forecasted properly to get correct irrigation demands.

It is becomes imperative therefore to develop a scientific background for the operation of such reservoirs. A model for the derivation of real-time optimal operating policy for a reservoir under a multiple crop scenario is proposed in the present study. Linear Programming Technique is used for optimising the various parameters. The reservoir storage and the soil moisture status are considered to be the principal state variables and the irrigation depths are considered to be the decision variables. An optimal allocation model is embedded in the integrated model to determine the water supply to different crops whenever there exists a competition amongst the crops. The model also serves as an irrigation-scheduling model that at any given fortnight specifies the amount of irrigation. For the development of the model the impact on crop yield due to water deficits and the effect of soil moisture dynamics on crop water requirements are taken into account. Moreover a root growth model is adopted to consider the effects of the varying root depths on the moisture transfer. A model is developed for dry (Rabi) season operation and does not require forecast of inflows since the reservoir system does not receive any inflow. However for forecasting the reference evapotranspiration dependability based approach has been adopted. The developed model is applied to the Chiller Reservoir System in Madhya Pradesh. To demonstrate the application of the LP model developed in this study, the following data were collected and processed:

1 Evapotranspiration data
2 Details of crops in the command area
3 Details of net returns from individual crops
4 Reservoir data
5 Soil properties

2 Reservoir Operation Models

Reservoir operation models can be classified as deterministic if the stream flows are assumed known and probabilistic or stochastic if only the probability distribution of the stream flows is known. Although the stochastic models are more complex and require more computational time, the information supplied by them is more useful and due to this reason, they are in vogue nowadays (NIH, 1991-92). In the present study the problem is related to the operation of reservoir for irrigation purpose and the problem can be well approximated by a function with linear relationships. Hence the Linear Programming formulation and optimisation is used. The further review is confined to the LP applications.

LP Models are probably the most popular optimisation models due to its simplicity and strong theoretical background (Narulkar, 1995). Application of LP to reservoir operation problems in a deterministic environment is suggested in Dorfman (1962). Narulkar (1995) can be referred description of other LP applications as applied to multi reservoir systems.

It has been established that the mathematical models are much popular techniques to derive the operating policy and evaluation of performance of a system. The policies coupled with a suitable forecasting model can be used for real-time reservoir operation. The real-time reservoir operation is concerned with the optimal operation of the reservoir system in accordance with the optimum release policy from the operation model for the inflow forecasts obtained from the forecasting model. The most important feature of the reservoir operation problem is the hydrologic uncertainty inherent in the inflows to the reservoir.

3 The Crop-Soil-Water-Atmosphere (CSWA) System and Water Requirements

Optimum allocation of water calls for an extensive understanding of CSWA system. Moreover, the role of water in the growth of the crop is also to be understood. The water requirement arises because of consumptive use to meet the growth requirements and evaporative demands of the atmosphere. The combined effect studied under the head of evapotranspiration that depends upon the wide variety of parameters, majority of them are climatic. A detailed description of estimation of evapotranspiration and the crop water requirement is given in Doorenboss and Pruitt (1977).

For the assessment of timing of application of irrigation water, the soil moisture status of the crop is an important parameter. Whenever the soil moisture status approaches a critical limit, the irrigation is applied. For this purpose the soil moisture status is to be monitored either by physical measurement or through the soil moisture accounting models. Soil moisture accounting models are more popular since it does not require lot of instrumentation to be installed in the field. Soil moisture accounting models can be formulated either by physical approach (Fedders et al., 1978) or Conceptual approach (Rao, 1987). The conceptual approach has been used by Rao et al.(1988) and Rao et al. (1990) for the problem of irrigation scheduling. Vedula and Mujumdar (1992) have utilised the conceptual model in their study. In the present study also the same concept is used.

4 Yield Response Function for the Crops

The soil moisture status of a crop at particular growth stage has direct impact on the yield of crops. In order to study the problem of optimal allocation it is necessary to understand and quantify crop response to soil moisture status in terms of yield. The function correlating the soil moisture, water application or the actual evapotranspiration to the yield of the crops are termed as crop-production function or yield response functions.

5 Integrated Modelling for Reservoir Systems and the Field Level Systems

The optimal operation of reservoirs supporting irrigation systems needs more emphasis in Indian context. Present trend is to model reservoir operation strategy on the basis of certain fixed demands and model irrigation scheduling process considering a predetermined availability of water. In real life situations however, the source of supply and the operating policy affect the soil moisture status and subsequently the yield from a crop. If the modelling perspective is broadened and the two processes are combined together better results can be expected. Dudley et al. (1971) pioneered the integration of the systems successfully in the determination of optimal irrigation timing under limited water supply using a Stochastic DP model. Dudley and his associates continued the research in the field by improving upon the models. Vedula and Mujumdar (1992, 1993), Mujumdar and Ramesh (1997) have presented a review of the works of Dudley.

6 Theoretical Background

The present section deals with the theoretical concepts used in the present study. Analysis of crop-soil-water-atmosphere system including the mathematical model related to the integrated LP model and the optimal cropping pattern are discussed.

7 The Crop-Soil-Water-Atmosphere System

For the assessment of timing of irrigation and quantity of water to be supplied, the soil moisture status is an important parameter. Whenever the soil moisture status approaches a critical limit, irrigation is applied. Hence, it is required to monitor the soil moisture status either through physical measurements or through soil moisture accounting models.

8 The Conceptual Model

In the conceptual model for the Crop Soil Water atmosphere system, the basic assumption is that the soil is assumed to act as a reservoir and the main inputs to the reservoir are rainfall irrigation and the main outputs are actual evapo-transpiration, percolation and drainage. The extent of the reservoir is considered to be up to the effective root zone at that time. The Soil Water reservoir is governed by a continuity equation:

$$\theta_i^{k+1} ED_i^{k+1} - \theta_i^k ED_i^k - IRR_i^k + AET_i^k = RF^k \qquad (1)$$

where, θ_i^{k+1} = Final soil moisture in a particular time stage k for a particular crop i (mm/cm)

ED_i^k = Effective root zone depth of a crop i in period k (cm)

θ_i^k = Initial soil moisture in the time stage k in for a crop i (mm/cm)

ED_i^{k+1} = Effective root zone depth of a crop i in period k (cm)

AET_i^k = Actual evapotranspiration in period k from crop i (mm)

RF^k = Rainfall in period k (mm)

IRR_i^k = Irrigation applied to crop i in stage k (mm)

The conceptual model stated by Equation 1 is used to compute the irrigation to be applied for the LP model with area as a decision variable. Figure 1 shows the sketch for the conceptual reservoir. In the context of the conceptual model two parameters are important

1) The variation of evapotranspiration with the available soil moisture & 2) The root zone depth growth.

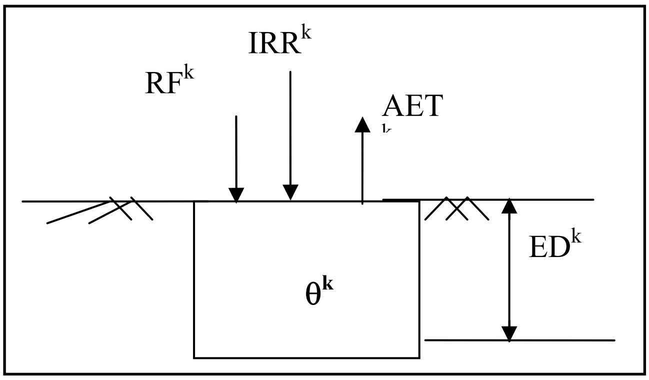

Figure 1 Conceptual model

9 Variation of Evapotranspiration with the Available Soil Moisture

The actual evapotranspiration is the function of the available soil moisture. In the present study the assumptions made by Doorenbos and Kassam (1979) are used.

$$AET_i^k = PET_i^k \quad \text{if} \quad a_{ai}^k \geq Zww \qquad (2)$$

Otherwise

$$AET_i^k = \frac{a_{ai}^k}{Zww} PET_i^k \qquad (3)$$

Where, AET_i^k = Actually occurred evapotranspiration from crop i in period k fortnight (mm)

PET_i^k = Potential evapotranspiration in a particular geographical location (mm)

Zww = Critical available moisture limit (mm/cm) and is calculated as

Zww = (Zf–Zw) d

Where, Zf = Field capacity for the soil (mm/cm)

Zw = Permanent wilting point for the soil (mm/cm)

d = Depletion factor and assumed to be 0.5 in the present study.

a_{ai}^k = Average available soil moisture over a fortnight (mm/cm) and is given by $a_{ai}^k = \dfrac{a_i^k + a_i^{k+1}}{2.0}$

where, $a_i^k = \theta_i^k - Zw$

a_i^k if < Zww

otherwise a_i^k = Zww.

Similar expression can be used for a_i^{k+1}

10 Root Zone Depth Growth Model

The root depth data in relation to the time stages are prepared according to Linear Root Growth Model (adopted by Narulkar, 1995). The model assumes that maximum root depth is achieved at the start of yield formation stage. It remains at the maximum depth till the maturity stage. A minimum depth of 15 cm is considered in the first fortnight to account for the conditions of bare soil and sparsely cropped area. The root depth model is shown in Figure 2.

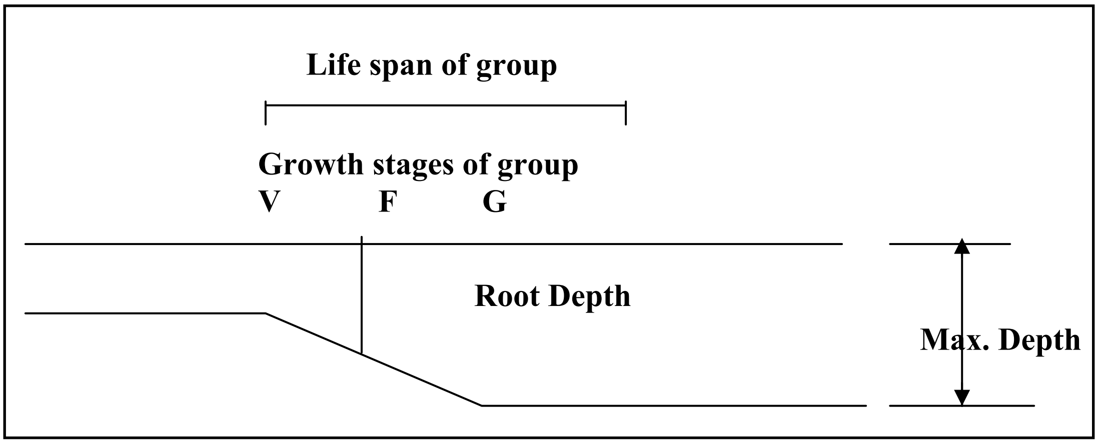

Figure 2 Root Depth growth model

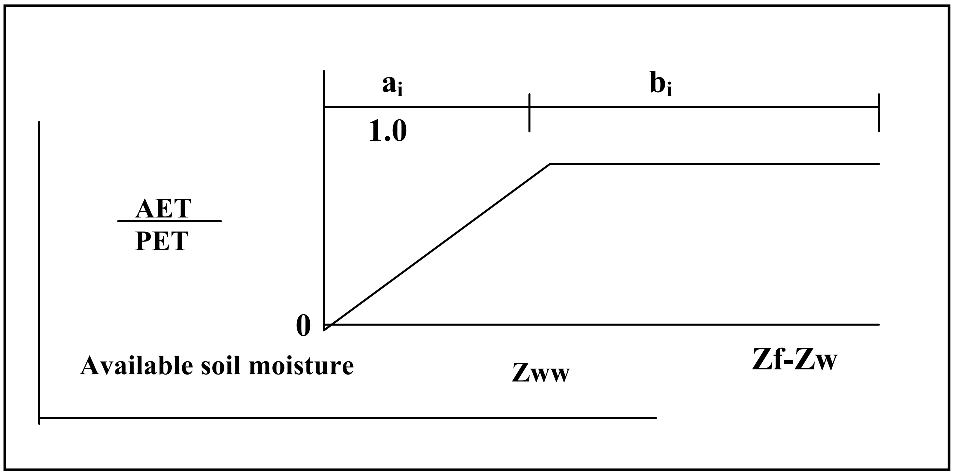

Figure 3 Relationship between the available soil moisture in the root zone and the ratio of actual evapotranspiration to potential transpiration

11 Relative Yield Ratio

The yield of a crop is affected by the water deficits. The rate of evapotranspiration also affects the yield and the rate of evpotranspiration is prone to reduction due to the available moisture content. There are many methods to model the phenomenon. However, the model used in the present study is the most commonly adopted model. The relative yields are computed on the basis of the expression given by Doorenbos and Kassam (1979)

$$\frac{Y_{ai}}{Y_{mi}} = 1 - Ky^k (1 - \frac{AET_i^k}{PET_i^k}) \quad (4)$$

In which $\frac{Y_{ai}}{Y_{mi}}$ is the ratio of actual yield to the maximum possible yield of a crop.

The other terms are explained before. The Equation (4) gives a yield ratio for a single period only. However, the aggregate effect of moisture deficits over all the fortnights of a crop growth is also to be evaluated. The final yield ratios computed for the crop various time periods of a season is computed by a multiplicative model (Rao et al., 1990). The determination of the yield ratio is very important since they reflect the operation policy for an irrigation system.

The expression is given by

$$\frac{Y_{ai}}{Y_{mi}} = \prod_{i=1}^{ncr} (1 - Ky^k)(1 - \frac{AET_i^k}{PET_i^k}) \quad (5)$$

12 Water Requirements of the Crops

The model derived for optimal cropping pattern uses predetermined irrigation demands. On the basis of this, the optimisation model selects an appropriate area for individual crop. The irrigation demands using the conceptual model stated in Equation (1). Substituting a value of critical soil moisture content instead of soil moisture in either of the fortnights k and k+1 and replacing the values of actual evapo-transpiration by potential evapotranspiration and rearranging the terms of Equation (1) we get irrigation requirements as

$$IRR_i^k = \vartheta_{cr} (ED_i^{k+1} - ED_i^k) + PET_i^k \quad (6)$$

Where, ϑ_{cr} = the critical soil moisture content below which the actual evapotranspiration may fall below the potential rate.

13 Integrated LP Formulation

For evaluating the optimal operating policy for reservoir supporting irrigation system, an Integrated Linear Programming Model has been formulated. The model integrates the reservoir level to a field level decision. It considers the soil-moisture status and the reservoir storage as the state variables and the applied irrigation depths as decision variables. The formulation is based on the conceptual model and the reservoir storage continuity relationships. Major emphasis is laid on maintaining soil moisture to such a state that the evapotranspiration from the crops takes place at potential rate. In the objective function the weighted sum of all the actual evapotranspiration values has been maximised. The weightages are assigned according to the yield response factors for individual crops in individual periods. The objective is to maximise the actual evpotranspiration rate to minimise the deficits in the yields. The available soil moisture in any time period in the objective function is indirectly maximised.

$$\mathrm{Max}Z = \sum_{i=1}^{ncr} \sum_{k=1}^{np} \left\{ \frac{a_i^k + a_i^{k+1}}{2.0} \right\} \frac{Ky^k}{Zww} \quad (7)$$

Subjected to the following constraints:

Constraint due to soil moisture continuity

$$\theta_i^{k+1} ED_i^{k+1} - \theta_i^k ED_i^k - IRR_i^k + \left\{ \frac{a_i^k + a_i^{k+1}}{2.0} \right\} \frac{PET}{Zww} = RF^k \quad (8)$$

and $\theta_i^{k+1} - a_i^{k+1} - b_i^{k+1} = Zw$ (9)

Physical bounds

$$\theta_i^{k+1} \le 4.0 \quad (10)$$

$$a_i^{k+1} \le 0.9 \quad (11)$$

Constraint due to reservoir continuity equation

$$A^k S^{k+1} - B^k S^k + \sum_{i=1}^{ncr} \frac{IRR_i^k * AREA_i^k}{Eff} = -ID - A_0 RE^k \quad (12)$$

$$S^{k+1} \le 31.1 \quad (13)$$

Where, Ky^k = yield response factors for a crop i in period k

S^k = reservoir storage at the beginning of period k

S^{k+1} = reservoir storage at the end of period k

A^k and B^k = Constants relating the storage to reservoir evaporation

ID = Industrial supply from the reservoir (mandatory release)

Eff = Overall efficiency

Ao = Area of spread at dead storage level

RE^k = Rate of evaporation in fortnight k

14 LP Model Formulation for Optimal Cropping Pattern

For evaluating the modified cropping pattern, another LP model has been used. In this model, irrigation depths to be applied are calculated from the Equation (6). The formulation is given in the following lines. The objective function is

$$\mathrm{Max}\ Z = C_1 X_1 + C_2 X_2 + C_3 X_3 \quad (14)$$

Subjected to the following constraints

Constraint due to total available area

$$X_1 + X_2 + X_3 \le A \quad (15)$$

Where X_1, X_2, and X_3 = the decision variables related to the area of individual crops and C1,C2, and C3 are cost in Indian rupees respective crops

A = Maximum area available for irrigation

Constraints due to area under individual crops:
The area under each crop is required to be constrained, so that there are lower and upper bounds on the area under each crop. The lower bounds indicate the minimum area that can be allocated to a crop while the upper bound indicates the maximum area that can be allocated to a crop. In the present study, the lower bounds have been defined for all the crops except cash crop while the upper bounds have been defined considering the present cropping pattern. The constraints can be expressed as

$$L_i \le X_i \le M_i \quad (16)$$

Where L_i corresponds to the lower bounds of area for i^{th} crop and M_i correspond to the upper bound on the area of individual crops.

Table 1 Optimum Cropping Pattern for Different Live Storage Values

Live storage (M cu m)	Area (ha) for different crops		
	Wheat (ordinary)	**Gram**	**Wheat (hybrid)**
4.3230	-	342.910	120.00
8.2379	-	427.580	500.00
12.3246	-	1084.015	500.00
15.8632	-	1100.000	855.00
20.7581	-	1100.000	1434.00
26.0986	300.0	1100.000	1700.00
28.8610	300.0	1100.000	1700.00
30.1250	300.0	1100.000	1700.00
31.1000	300.0	1100.000	1700.00

15 Stochastic Analysis of Evapotranspiration

It is stated earlier that the data regarding the climatic factors is uncertain in nature and the determination of these factors beforehand is impossible. However there is a general trend to assume the expected values for these factors and carry out the operation. The concept does not give a clear-cut picture of the actual scenario and due weightage to the individual growth stage of the crops is also not given. Present study proposes a different method of taking the expected values for the climatic factors. The method of analysis starts with the computations of dependability values of reference evapotranspiration factors from the available data. The dependability of realisation of any stochastic variable is defined as the probability of equalling or exceedance of that variable with a particular value.

Mathematically,

$$P(x \geq X) \tag{17}$$

Where, P(.) is the probability and x is the variable under consideration. X is a stipulated value of the variable that is equalled or exceeded with the probability. A traditional method of estimation of the dependability value is the use of standard frequency formulae. (e.g. Wiebull's formula or Hazen's' formula). In the present study a detailed probability analysis for the data is performed. The data is fitted to standard probability distribution and the best fitting distribution is tested through the Kolmogorov Smirnov Test (Haan, 1977).

Once the values corresponding to different dependability are evaluated it is required to assume different dependability for different values of reference evapotranspiration in different growth stages. The analysis is performed on the basis of the yield response factor values. Higher yield response factor value signifies higher sensitivity towards the deficits and hence a higher level of dependability is assumed for the evapotranspiration data and a lower level of dependability is assumed for the rainfall data. This will ensure a higher value of irrigation require for the crop in the sensitive period. Subsequently the crop will be safeguarded against any ill conditions of moisture content. The computed soil moisture status of the crops is used in the next fortnight for the computations of the demand.

16 Crop Simulation Model

The optimisation model yields some irrigation depth values that are based on assumed values for the reference evapotranspiration based on dependability. However, the actually occurred evapotranspiration value differs from these values largely and hence before going in to the next fortnight the soil moisture status is to be updated with the applied irrigation and actually occurred climatic factors. The formulation for crop simulation is presented in following lines.

First compute the final soil moisture with the following relation

$$\theta_i^k = (\theta_i^{k-1} ED_i^{K-1} + IRR_i^K - Fkc_i^k APET^K + ARF^K)/ED_i^K \tag{18}$$

Where $APET^k$ Corresponds to actually occurred potential evapotranspiration and ARF^k is the actually occurred rainfall value in the fortnight k. Fkc_i^{k+1} is crop evapotranspiration coefficient. Other notations are defined already.

If $\theta_i^{k+1} < 3.1$

$$ED_i^{k+1}\theta_i^{k+1} = \left[\theta_i^k ED_i^k + IRR_i^{k+1} - \frac{Fkc_i^{k+1} APET^{k+1}}{2.0} + \frac{Fkc_i^{k+1} APET^{k+1}}{2.0} Zw + ARF^{k+1}\right] \div (ED_i^{k+1}) \frac{Fkc_i^{k+1} APET^{k+1}}{2.0} \tag{19}$$

otherwise,

$$\theta_i^k = \theta_i^{k-1}\left[ED_i^{k-1} - \frac{Fkc_i^k APET}{2.0}\right] + \frac{Fkc_i^k APET}{2.0} Zw + ARF^K + IRR_i^k - \frac{Fkc_i^k APET}{2.0} \div ED_i^k \tag{20}$$

Otherwise,

$$\theta_i^K = \left\{\theta_i^{k-1}\left[ED_i^{K-1} - \frac{Fkc_i^K APET}{2.0}\right] + IRR_i^K + 2.0\frac{Fkc_i^k APET}{2.0} Zw\right\} \div \left(ED_i^k - \frac{Fkc_i^K APET}{2.0}\right) \tag{21}$$

17 Results and Discussions

A separate computer program was run before the real time operation program to determine the optimum cropping pattern for all the possible storage values. The results of optimum cropping pattern determination are stated in Table 2. The results indicate that from storage level of 31.10 M cu m to a storage level of 26.06 M cu m the cropping pattern is same as that has been adopted in the project formulation. However, below the storage level of 26.06 M cu m the cropping pattern changes suddenly and Wheat (ordinary) is not recommended by the model. Area of Wheat (Hybrid) also gets reduced after this level. Area for Gram is full up to storage level of 15.83 M cu m. After this level the area reduces. The change in cropping pattern indicates that the water use efficiency is maintained.

18 Results from Real-Time Operation Model

The real-time operation model as discussed earlier gives an optimal operating policy for the available storage in the present fortnight considering the future (Azamathulla et al. 2005). The model also yields the values of irrigation to be applied to individual crops in the fields. In the wake of deficient water supplies the model distributes the available water over the time for different crops optimally. Two sample results of the present model in the form of the values of the variables are stated in Tables 2and 3. The available moisture to the crops is not affected and mostly the soil remains at the upper limit of the available soil-moisture. This is due to the reason that the cropping pattern is predicted according to the availability of the storage in the reservoir. The results are indicative of successful application of the real-time operation strategy proposed in the present work.

19 Relative Yield Ratios

Relative yield ratios computed for different crops at different live storage values are shown in Table 4. The relative yield ratios for all the crops become one if live storage in the reservoir is equal to or greater than 28.89 M cu m.

Table 2 Sample Results Showing The Soil Moisture, Available Soil Moisture, Storage, Irrigation to be applied, for Different Crops for Real-Time Reservoir Operation Model

Live Storage in the Reservoir 31.1 M cu m

PARAMETER	FORTNIGHT										
	1	2	3	4	5	6	7	8	9	10	11
Reservoir Storage (mcm)	29.28	28.17	26.30	22.22	19.68	14.64	10.87	5.62	4.24	3.63	3.60
Crop	WHEAT (ORDINARY)										
1) Soil Moisture (mm/cm)	3.76	3.89	3.84	3.07	3.54	3.30	3.22	3.17	4.0	- -.	- -
2) Available soil Moisture (mm/cm)	0.9	0.9	0.9	0.87	0.9	0.9	0.9	0.9	0.9	- -	- -
3) Applied Irrigation (mm)	53.62	90.63	92.87	36.04	163.9	8.44	23.02	19.94	102.6	- -	- -
Crop	GRAM										
1) Soil Moisture (mm/cm	3.90	3.07	3.28	3.15	3.4	3.28	3.66	3.23	3.47	- -	- -
2) Available soil Moisture (mm/cm)	0.9	0.87	0.9	0.9	0.9	0.9	0.9	0.9	0.9	- -	- -
3) Applied Irrigation (mm)	68.76	22.27	60.67	41.59	26.96	37.64	53.15	0.00	33.17	- -	- -
Crop	WHEAT (HYBRID)										
1) Soil Moisture (mm/cm)	- -	- -	- -	4.00	3.06	3.48	3.32	3.28	3.38	3.18	3.19
2) Available soil Moisture (mm/cm)	- -	- -	- -	0.9	0.86	0.9	0.9	0.9	0.9	0.9	0.9
3) Applied Irrigation (mm)	- -	- -	- -	94.21	37.19	127.9	78.89	162.9	0.00	36.09	0.0

Table 3 Sample Results Showing The Soil Moisture, Available Soil Moisture, Storage, Irrigation to be applied, for Different Crops for Real-Time Reservoir Operation Model

Live Storage in the Reservoir 4.323 M cu m

PARAMETER	FORTNIGHT										
	1	2	3	4	5	6	7	8	9	10	11
Reservoir Storage (mcm)	3.78	3.31	3.21	2.21	1.75	1.35	1.08	0.688	0.405	0.198	0.179
Crop	GRAM										
1) Soil Moisture (mm/cm)	3.90	3.91	2.68	3.77	4.0	3.87	3.37	3.12	2.91	- -	- -
2) Available soil Moisture (mm/cm)	0.9	0.9	0.48	0.9	0.9	0.9	0.9	0.9	0.82	- -	- -
3) Applied Irrigation (mm)	68.76	57.98	0.0	127.1	43.99	20.36	0.0	10.67	4.11	- -	- -
Crop	WHEAT (HYBRID)										
1) Soil Moisture (mm/cm	- -	-	- -	4.0	3.06	3.50	3.32	3.28	3.33	3.52	3.19
2) Available soil Moisture (mm/cm)	- -	- -	- -	0.9	0.86	0.9	0.9	0.9	0.9	0.9	0.9
3) Applied Irrigation (mm)	- -	- -	- -	53.71	37.19	80.14	77.44	95.15	55.83	39.67	0.00

Table 4 Relative Yield Ratio for Different Live Storage Values Computed With Real-Time Reservoir Operation Model

Live storage (M cu m)	Area (ha) for different crops			Relative yield ratio for different crops		
	Wheat (ordi)	Gram	Wheat (hyb)	Wheat (ordi)	Gram	Wheat (hyb)
4.3230	-	342.910	120.000	-	0.982	0.975
8.2362	-	427.58	500.000	-	1.000	1.000
12.3246	-	1084.015	500.000	-	0.896	1.000
15.8632	-	1100.000	855.000	-	0.898	0.995
20.7581	-	1100.000	1434.00	-	0.951	0.944
26.0986	300.0	1100.000	1700.00	1.000	1.000	0.960
28.8610	300.0	1100.000	1700.00	1.000	1.000	1.000
30.1250	300.0	1100.000	1700.00	1.000	1.000	1.000
31.1000	300.0	1100.000	1700.00	1.000	1.000	1.000

20 Conclusions

A real-time model using an integrated Linear Programming Model for a reservoir system meant for irrigation has been developed in the present study to obtain an optimal reservoir operating policy that is incorporating field level decisions while taking a decision for the releases from the reservoir. From the analysis following conclusions can be drawn:

- The developed model can be successfully applied to the real-life case study of an irrigation supporting reservoir system.
- The model ensures an optimum reservoir release over different time periods.
- It also assures optimum allocation of the available water over the different crops in the fields.
- While allocating the water to different crops in the fields the model takes into account the critical growth stages of the crops and allocates sufficient water to each crop to safeguard it against any ill effects of the deficits.
- The optimum cropping pattern model used in the study will restrict the irrigation to be productive and the wastage of water can be reduced.
- The stochastic analysis of evapotranspiration based on dependability studies

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