International Journal of Agricultural Engineering, Vol. 3 No. 1 (April, 2010) : 179-183

A Case Study :

Simulation model for evaluation of irrigation project

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Accepted : ***March, 2010***

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Irrigation water is released in canal network as per demands of the farmers in the command area. However, the effect of water release policies on crop yield and subsequent net benefits can not be ascertained as the irrigation water releases are often decided without considering the heterogeneity of the command area in terms of soils and crop stages. Hence evaluation of irrigation project is necessary as it helps to rectify water release policies and proposes corrective measures for efficient water management. In this study, mathematical simulation model was developed for the evaluation of irrigation project in terms of net benefits and applied to Punegaon project in Upper Godavari basin in Maharashtra. The developed model considers water distribution to the crops according to water release policy to be evaluated and estimates the crop yield by considering the response of crop to water applied at its different growth stages. The yield values are further converted into the net benefits. The model considers all the parameters that influence the yield. These include climate, soil, crop, losses in the irrigation network etc. The results of case study indicate that the distribution of water with respect to time is more important apart from total quantity of water applied to the crops. The crop yield is adversely affected if the crop experiences water stress during its yield sensitive stages.

Key words : Soil water balance, Crop growth model, Irrigation scheduling, Punegaon irrigation project

The planning for irrigation water management consists of preparation of preliminary irrigation programme for allocation and distribution of water resources to different crops in the command area. The crop yield is mainly dependent on amount of water delivered at particular crop growth stage. It is therefore necessary to know the response of the command area as a whole and its units *i.e.* outlet or minor, to different water release policy in terms of crop yield and net benefits prior to finalizing the particular water release policy. Due to climatic variability and unforeseen circumstances it is often required to modify the water release policy while the irrigation system is in operation. Under such circumstances it is necessary to have appropriate tool that aids in evaluation of several water release policies for comparison and to select appropriate one.

A number of evaluation studies have been carried out by various researchers for evaluating various water release policies for improving the performance of irrigation project. Loucks (1981) stated that behavior of the irrigation system is very well reflected by its evaluation studies. He further highlighted the importance of evaluation in better understanding the system. Biswas (1990) emphasized the importance of monitoring and evaluation of irrigation projects for future water management improvement. He further asserted that monitoring and evaluation should be given equal importance as planning and design of the project. Smout (1996) carried out evaluation of Takeo Irrigation Project in Cambodia and highlighted positive impacts of the projects through evaluation studies. Isidoro et al. (2004) carried out water balance and irrigation performance analysis of La Violada irrigation district in Spain and concluded that system can be better managed for the future by way of evaluation studies. Labadie (2004) highlighted the importance of understanding the behaviour of reservoir system for maximizing the beneficial uses of the projects. Evaluation studies reported by Gorantiwar and Smout (2005) emphasized the importance of application of required quantity of water at required time depending on crops and the type of soil.

Considering the importance of evaluation; the present study was undertaken to assess the response of command area in terms of net benefits for existing water release policy and investigating the causes of low performance. For this purpose, mathematical simulation model was developed which examines the response of a specified water release policy on crop yield and net benefits. The model considers the heterogeneity of command area with respect to soil, climate and canal network. This paper describes the model used for evaluation study of Punegaon project and results of the evaluation.

Mathematical simulation model was developed for evaluation of irrigation project. It is based on the concept of distributing the released water through the canal to different crops according to a specified water release policy. The model considers all the parameters that influence the crop yield. These include climate, soil, crop, losses in the irrigation network etc. The model performs the evaluation for canal water releases at the head of the canal. Soil moisture balance at root zone is carried out on daily basis. The inflow parameter of soil moisture balance comprises of rainfall and irrigation (derived from the canal water releases at head) and outflow parameters are evapotranspiration and deep percolation. Initial soil moisture content is considered as known. The initial soil moisture is assumed at i) field capacity, ii) 50 % available moisture and, iii) wilting point for planting in rainy, winter and summer seasons, respectively. If pre-sowing irrigation is given, the soil moisture content before pre-sowing irrigation is considered at wilting point. The initial soil moisture is then computed by carrying out a water balance over the period from pre-sowing irrigation to first crop irrigation. The reference crop evapotranspiration is estimated by Penman-Monteith method (Smith, 1991). Based on the formulation of Doorenbos and Kassam (1986), actual evapotranspiration is considered as equal to maximum evapotranspiration until the readily available soil water has been depleted. Beyond this depletion, actual evapotranspiration becomes smaller than maximum crop evapotranspiration until the next application of the water and its magnitude depends on remaining soil water content and maximum crop transpiration. The actual evapotranspiration is worked out using equations (1) and (2)

$$\mathbf{ETa_t = ETm_t}$$

$$\textbf{If } (\theta_t^R - \theta_w^R)\, Z_t \geq (1-p)\,(\theta_f^R - \theta_w^R)\, Z_t \qquad (1)$$

$$\mathbf{ETa_t} = [(\theta_t^R - \theta_w^R)\, Z_t \; ETm_t] \,/\, [(1-p)\,(\theta_f^R - \theta_w^R)\, Z_t] \qquad (2)$$

$$\textbf{If } (\theta_t^R - \theta_w^R)\, Z_t < (1-p)\,(\theta_f^R - \theta_w^R)\, Z_t \qquad (3)$$

where, ETa_t is actual evapotranspiration on t^{th} day ; ETm_t is maximum crop evapotranspiration on t^{th} day; θ_t^R is volumetric soil moisture content (SMC) in the root zone depth on t^{th} day; θ_w^R is volumetric SMC in the root zone depth on t^{th} day at wilting point; θ_f^R is volumetric SMC at field capacity; Z_t is root zone depth on t^{th} day in mm and p is soil water depletion factor.

The stage wise crop growth model (equation 3) proposed by Stewart and Hagan (1973) is used for the estimation of crop yield.

$$\frac{\mathbf{Y_a}}{\mathbf{Y_m}} = \mathbf{1} - \sum_{s=1}^{ns} \mathbf{Ky_s} \left(\frac{\mathbf{ETm_s - ETa_s}}{\mathbf{ETm_s}} \right)$$

where, Y_a = Actual crop yield (kg/ha); Y_m = Maximum potential yield (kg/ha); *s* = Subscript for crop growth stage; Ky_s = Yield response factor for s^{th} stage; ETm_s = Maximum crop evapotranspiration for s^{th} stage (mm); ETa_s = Actual crop evapotranspiration for s^{th} stage (mm); ns = Total number of crop growth stages.

The net benefits per unit area of irrigated land are estimated by calculating the cost incurred and benefits derived from cultivation of the crops. The flow chart of developed model for simulation of crop yield and net benefits is presented in Fig. 1

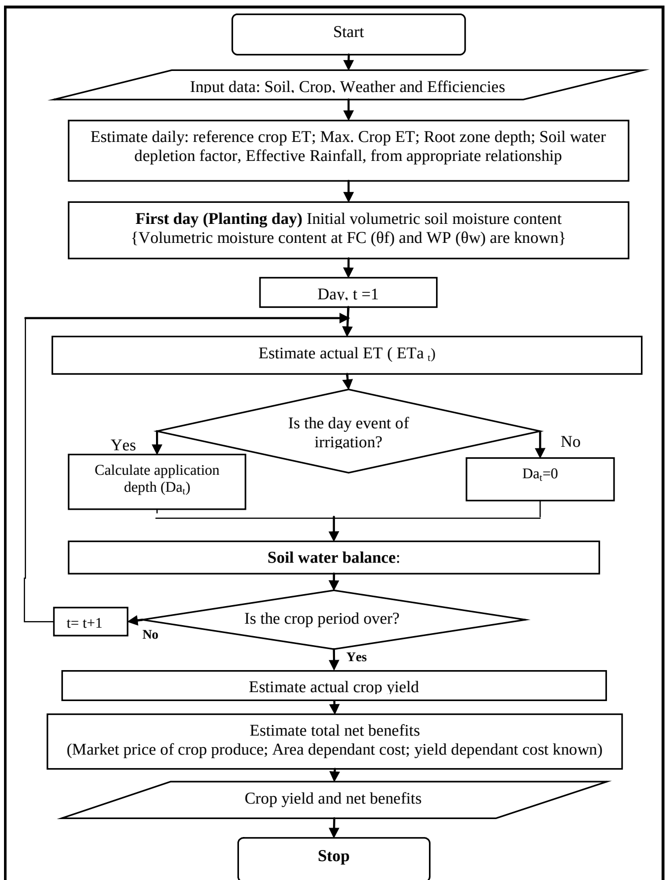

Fig. 1 : Flow chart of simulation of crop yield and net benefits

Description of the study area:

Punegaon dam is constructed across river Unanda at village Punegaon (20^0-21'N latitude, 73^0-50'E longitude) in Dindori taluka of Nashik district in Maharashtra. River Unanda is sub-tributary of river Godavari and originates in mountainous terrain forming ridge of Tapi and Godavari valley near village Karanjkhed. The length of the river from origin to dam site is 13.5 km. Punegaon dam having 1803 m length comprises rolled earth filled embankment with 122 m masonry spillway. The work of the project started in 1985. The dam portion was completed in 2003; however canal work is still in progress. The gross storage capacity of the dam is 20.29 Million cubic meters. The catchment area of the project is 66 km^2 and area under submergence is 372 ha. The average annual rainfall in the catchment is 707 mm. The yield of the project with 50 % dependability is 47.10 Mm^3. It has 63 km long left bank canal with irrigable command area of 5483 ha.

The crops are grown in three seasons namely *Rabi* (winter), hot weather (summer) and *Kharif* (rainy). Normally there is no demand of water during *Kharif* as the major portion of rainfall is received during this season and hence there are no rotations during *Kharif* season. Water is delivered from the reservoirs to the crops during *Rabi* and hot weather seasons

Main crops grown in the command of the project are sugarcane, grapes, wheat, gram and cauliflower.

Direct outlets/minors/distributaries from main canal are considered as unit for this study. Evaluation study was carried out for the year 2006-07 when 5 units were provided with irrigation in six rotations. The irrigation details of Punegaon project for the year 206-07 are given in Table 1.

Table 1: Irrigation details of Punegaon project for 2006-07

Rotation number	Rotation start day	Rotation end day
1	01/12/2006	18/12/2006
2	15/01/2007	23/01/2007
3	14/2/2007	22/02/2007
4	25/03/2007	10/04/2007
5	9/04/2007	06/05/2007
6	19/05/2007	31/05/2007

The evaluation of Punegaon irrigation project in Nashik district of Maharashtra in upper Godavari basin was performed with the help of the developed simulation model by considering cropping pattern, water releases at the head of the canal and climatic data of the year 2006-07. The model simulated unit wise, crop wise water use and corresponding crop yield and net benefits. Variations of moisture content of root zone of various crops in each unit were also simulated with the help of the model.

It was found that minimum net benefits per unit area from the project were Rs. 63438 /ha; which were found to be on the higher side (Government of Maharashtra, 2009) as compared to benefits of other major projects in the state. This is mainly due to more percentage of grapes and sugarcane in the cropping pattern of the project and use of drip irrigation method for the grapes.

The net benefits per unit area and benefits per unit of water for different distributaries of the project are shown in Fig. 2 and 3. It is seen from these figures that the net benefits per unit area and water applied for distributary 2 are Rs. 74391 /ha and Rs. 102292 /(ha-m), respectively. These benefits are more than benefits of other distributaries of the project.

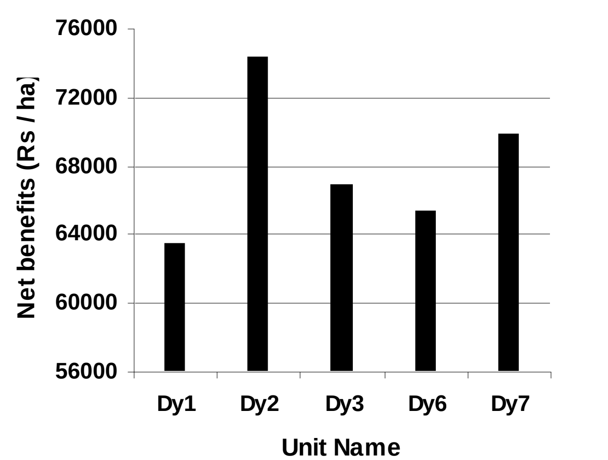

Fig. 2 : Unit wise net benefits per unit area for Punegaon project

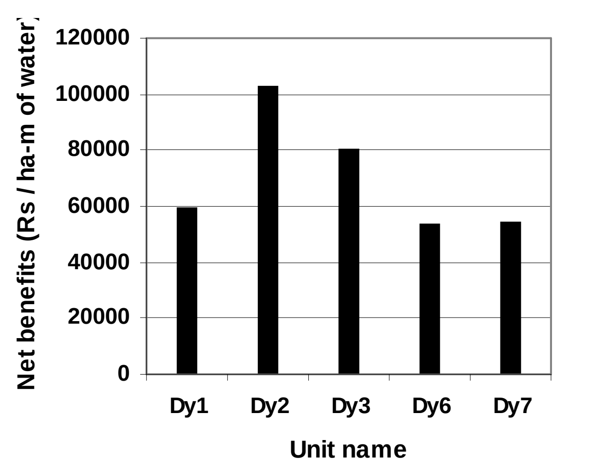

Fig. 3 : Unit wise net benefits per unit of water for Punegaon project

On the other hand average water application depth (Fig. 4) of distributary 2 is minimum (72cm) compared with other distributaries of the project. The analysis showed that more benefits are contributed to large proportion of area under irrigation for grapes (42%) and sugarcane (8%) on distributary 2. Drip irrigation method was used for grapes and hence water was efficiently used. Average depth of water application was maximum (128 cm) on distributary 7. There were two crops namely grapes and cauliflower irrigated on this distributary. The percentage areas of grapes and cauliflower were 37% and 63%, respectively. Analysis shows that since more water was available, both the crops received required quantity of water. But still it was observed that the yield of the cauliflower was much below the maximum expected yield. The detailed analysis showed that the time of irrigation water supply did not match with sensitive growth stages of cauliflower. This has resulted into reduction of the yield of cauliflower. The results of variation of moisture content in the root zone of cauliflower on distributary 7, obtained from simulation model (Fig. 5) confirms this fact. The model depicts that moisture content in root zone of cauliflower was much below allowable depletion level during initial and middle stages of growth period. Thus the supply of irrigation water irrespective of time does not serve the purpose unless crop gets water as per its yield sensitive stages for desired crop production.

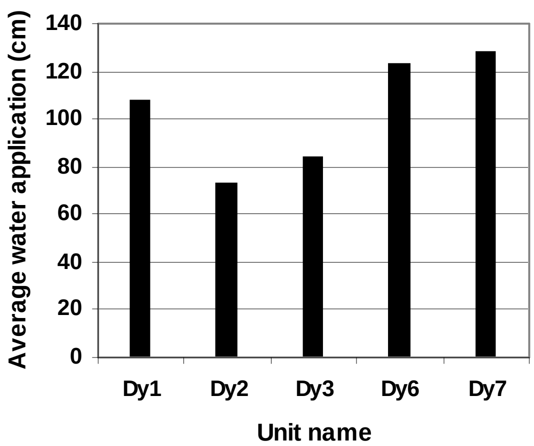

Fig. 4 : Unit wise average water application depths for Punegaon project

The analysis further shows that the benefits per unit area are mainly dependant on soil type for similar cropping pattern and irrigation methods. It is observed that benefits per unit area of distributary 2 are more (Rs. 74391 /ha) than distributary 1 (Rs. 63438 /ha) even though water application depth for distributary 2 is less (72 cm) than distributary 1 (108 cm). This is mainly due to drip irrigation method and favorable soil like clay on distributary 2. The sandy loam soil on distributary1 has less water holding capacity compared to clay soil on distributary 2 and hence as indicated by simulation results, more water application on distributary 1 led to deep percolation.

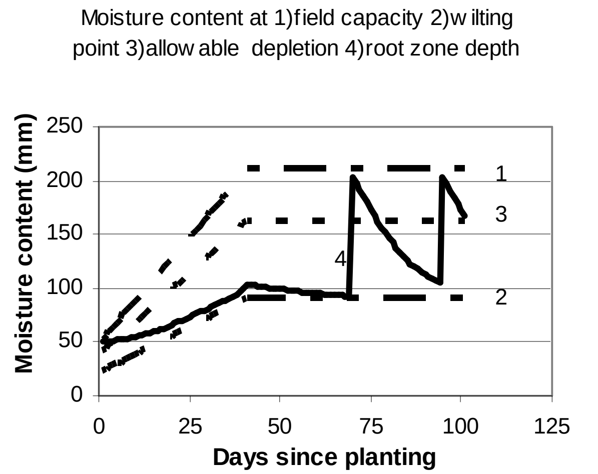

Fig. 5 : Variations in the moisture content of root zone of cauliflower on distributary 7of Punegaon project

Conclusions:

This paper has emphasized the need of considering appropriate climatic, soil, crop and command area parameters to estimate crop yields and benefits while evaluating the irrigation project. The results of evaluation study indicated that the type of soil, water application depth, irrigation method and irrigation interval influence the net benefits per unit area and per unit water applied. The evaluation study also indicated that the drip irrigation has the potential to use water efficiently. Application of large quantity of water than required may not result into more production if water holding capacity of the soil is less. Benefits of the irrigation projects can be maximized by releasing the irrigation water at appropriate interval, so those crop water requirements at yield sensitive stages of majority of crops in the command area are met.

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