CHAPTER 7: CROP CALENDAR ADJUSTMENT STUDY USING GENETIC ALGORITHM

7.1 INTRODUCTION

The operating rules for multipurpose reservoir systems should specify how the total demand could be met with the available supply of water from the system. The operating policies are generally defined by a set of rules that specify either reservoir target storage volume or target release. Generally, a reservoir system is designed based on the various parameters viz., inflow, command area requirement and type of crop to be cultivated, water requirement of the crop etc. In many practical situations, generally the operating policies are established at the planning stage of reservoir to meet the planned demand. However, after a few years of experience, the farmers may cultivate different crops in their own interest which can fetch them more benefit. Hence the operating rules have to be revamped in the light of fulfilling the requirement of changed cultivation scenario. The evaluation of alternative operating rules in terms of system performance through simulation model studies is needed before implementing them in practice. For the model study, the operating policy should take into account many factors such as water allocation, stream flow regulation and decision making regarding advanced scheduling of water release etc.

With the change in economic scenario, climate and attitude of the farmers, the necessity for proper management and optimum utilization of available water is gaining much importance. A large body of literature on the use of optimization and simulation models for water resources planning and management are reported by Yeh (1985), Simonovic (1992), Wurb (1993) and Labadie (2004). Models like linear programming, dynamic programming and variance of them work under rigid framework and it is very cumbersome to make the model flexible for more realistic modeling. Cancelliere et al. (2002) suggested a combined use of a soil water balance model, dynamic programming and neural network techniques for deriving operating rules of an irrigation supply reservoir. Teegavarapu and Simonovic (2002) used a stochastic search technique-simulated annealing (SA) to optimize the operation of multi-purpose reservoir. Kumar and Reddy (2006) used a metaheuristic technique called Ant Colony Optimization to derive operating policies for a multi-purpose reservoir system. Kumar et al., (2009) adopted Folded Dynamic programming for developing optimal reservoir operation policies for flood control. Heuristic models like Genetic Algorithm (GA) are highly suited to optimize the reservoir operation, as it is highly flexible. Genetic algorithm is one of the most often used optimization tool, used by many researchers for its efficiency in fast convergence to optimal solution.

The use of GA was first proposed in 1975 (Holland, 1992), which is based on Darwin's principal of evolution. GA is a search procedure based on the mechanism of natural selection and natural genetics, which combine the artificial survival of the fittest with genetic operators abstracted from nature. GA stimulates mechanisms of population generation and natural rules of survival. It relies on collective learning process within a population of individuals. Many application of GAs are reviewed by Goldberg (1989) and Davis (1991). Raju and Kumar (2004) used GA technique to evolve efficient cropping pattern for maximizing benefits for an irrigation project considering constraints viz., continuity equation, land and water requirement, crop diversification and restriction on storage. Xia et al., (2005) proved that the real-value coding is significantly faster and can produce better results when compared with binary coding for optimal reservoir dispatching. Kumar and Reddy (2006) suggested GA model for obtaining an optimal operating policy and optimal crop water allocations from an irrigation reservoir. Neelakantan and Pundarikanthan (2000) suggested a hedging rule based simulation-optimization procedure for improving the reservoir operation performance of a water supply reservoir system. Safavi et al., (2009) focused on the conjunctive use of surface water and ground water for irrigation by using simulation-optimization model. Ahmadi et al., (2010) presented GA-KNN (Genetic Algorithm – K Nearest Neighborhood) optimization model which can incorporate the utility functions of the water users and the stakeholders as well as their relative authorities on the water allocation process.

The Sathanur irrigation system consisting of Sathanur reservoir located across the Ponnaiyar River near Sathanur village in Thiruvanamalai District, Tamilnadu, India, is chosen for the analysis. Few literatures are available about Sathanur irrigation system. Santhi and Pundarikanthan (1997) evaluated different performance indicators for the Sathanur irrigation system for the year 1993 – 1994. Santhi and Pundarikanthan (1999, 2000) developed management information system and scheduling of canals for effective utilization of water. Santhi et al., (2002) developed an optimization model coupled with simulation model for finding the optimal percentage of gate opening in the canal. In the present study, genetic algorithm is used for maximizing net benefit of paddy crop in the Sathanur irrigation command area. A combined water balance simulation – optimization model is developed in which optimization is the outer driven model and water balance simulation model is the inner one.

7.2 THE PRESENT SCENARIO

Sathanur reservoir system has two types of command area viz., direct command and indirect command. Those command area which are getting irrigation water directly from the canal, or distributaries or direct outlets etc. are called direct command. Those command area which are getting irrigation water through available system of ground–level irrigation tanks are called indirect command. The irrigation ground-level tanks are shallow and small reservoirs formed by constructing earthern embankment to dam stream and to store water, which in-turn is used for irrigation purpose (Jayatilaka et al., 2003). Water released from Sathanur reservoir is stored in these tanks and used for irrigation. Li and Gowing (2005) adopted a daily water balance approach to simulate the dynamic behaviour of tank storage. Even before the construction of Sathanur reservoir, the cultivation of crops (indirect command) is carried out through the release from system of tanks available in the command. Hence the indirect command (tank irrigation) is given priority over the direct command (through canal) even though the command area in indirect command is less compared to the area of direct command. This system is a water-deficit irrigation system where the water is collected in the reservoir during North-East monsoon (Oct. - Dec.) and crops are cultivated after the rainfall season.

7.3 **SCOPE OF THE STUDY**

In this study, only the detailed analysis on releases to the direct command and tanks from the Sathanur reservoir is considered and the analysis of the release and distribution of water from the tank are not considered. Hence the cultivation of crops in the indirect command (tank command) is beyond the scope of this research. Water is released for irrigation for about four months, between December and April. The direct command (15200 ha) gets irrigation for the cultivation of groundnut crop which is an Irrigated Dry

(ID) crop. From the Sathanur reservoir, the tanks get water for the cultivation of paddy (wet crop) (indirect command) in three spells in September, December, January and February. The overall conveyance efficiency of the distribution system is 66% as the canals and distributories are well maintained with good lining and pitching (PWD, 1993). The direct command will not receive supply, whenever there is supply to tanks.

Though the direct command is designated for groundnut (ID) crop, most of the farmers are cultivating paddy crop, conjunctively using irrigation release for ID crop and ground water source. Since there is no restriction for use of ground-water and electricity is free for farm use, farmers are extracting the ground water to compensate the inadequacy in the irrigation release through canals. In this system, the release operational plan is prepared by the Executive Engineer in consultation with the farmers. Hence, the farmers are well aware of the release and further it is found that the farmers' associations at various levels are active. The scheduling and operation of this irrigation system mainly aims at equity. However, when the water availability is very low, achieving the equity over the entire command area can seriously affect the supply-demand ratio and thus the crop production. In the present condition, there is almost no rainfall during the crop growth season as the crops are started after the rainfall season.

7.4 PROBLEM DESCRIPTION

The Sathanur irrigation system is designed for supplying irrigation water to ID crop (groundnut) during post monsoon period along with the supply of water to system of tanks for indirect command. The total direct command area of the system is 152 million m^2 (15200 ha). The customary practice of the farmers was to start groundnut crop, in the II period of December month every year. However, for the past few years, the farmers in the Sathanur command are consistently cultivating paddy crop instead of groundnut crop in the post monsoon period. This is due to the increased net benefit of paddy crop over groundnut and also free supply of electricity to the farmers to pump the ground water for their irrigation purposes. This violation leads to inadequacy of irrigation water for paddy crop, as the Crop Water Requirement (CWR) of paddy is more than the CWR of groundnut crop. The farmers are extracting the ground water to compensate this inadequacy. However, the small farmers who are not having tube well or dug well find it difficult to get the required amount of water for their paddy crop. This leads to water stress to the paddy crop.

The average annual inflow into the Sathanur reservoir was found to be 314.08 million m^3. The average total annual demand from the system is about 246.79 million m^3. Each month is divided into three periods. First period consists of first ten days of each month. Second period consists of second ten days of each month and III period consists of the balance days of each month. Table 7.1 presents the different demands considered in this research and their priorities. Among different supplies, drinking water supply is given top priority.

Table 7.1 Various water demands in Sathanur irrigation system

Sl. No.	Type of demand	Priority	Quantity required per period in million m^3	Season	No. of Periods of demand per year
1.	Drinking water demand	1	Refer table 3.4		
2.	Tank demand	2	Refer table 3.4		

3.	Direct command demand for paddy crop	3	About 10	Between I period of September & III period of January	Continuous 14 periods
04	ID crop(groundnut) demand, if cultivated along with paddy in the December II period	4	Average 6.35	From II period of December to II period of March	10 continuous periods
05	Down stream side Thirukoilur barrage demand for stabilizing the second paddy crop	5	Refer table 3.4		

* Priority 1 is the top priority and priority 5 is the least priority.

Paddy crop is cultivated in the same period instead of designated groundnut crop which leads to water stress to the crop. Though farmers are not authorized to grow paddy, most of the farmers are growing paddy and managing the water deficit with local ground-water sources. Hence the practice may now be regularized by the government with proper scientific analysis. Generally paddy cultivation starts in the rainfall season as the rainfall may not affect the paddy crop; but which is not so in the case of groundnut crop. However, the current unauthorized practice of growing paddy starts after rainfall season and hence the effective rainfall contribution to the crop is not being utilized. Hence the irrigation release dates should be re-evaluated while authorizing the paddy crop. Therefore the cultivation of paddy crop may be advanced or postponed from the existing starting period (crop calendar of paddy crop). Farmers' opinion for altering the crop calendar of paddy crop is also obtained by administering a questionnaire in local language in the Sathanur command. Since the crop calendar adjustment of paddy crop fetches them more benefit with less extraction of ground water source, the farmers are interested in changing the crop calendar of paddy crop. In the present study, GA based crop calendar adjustment model is formulated and applied to evolve a suitable crop period to yield maximum net benefit while meeting the primary demands viz., the drinking water demand and tank demand. Figure 7.1 presents a bi-level flow chart for combined simulation - optimization model.

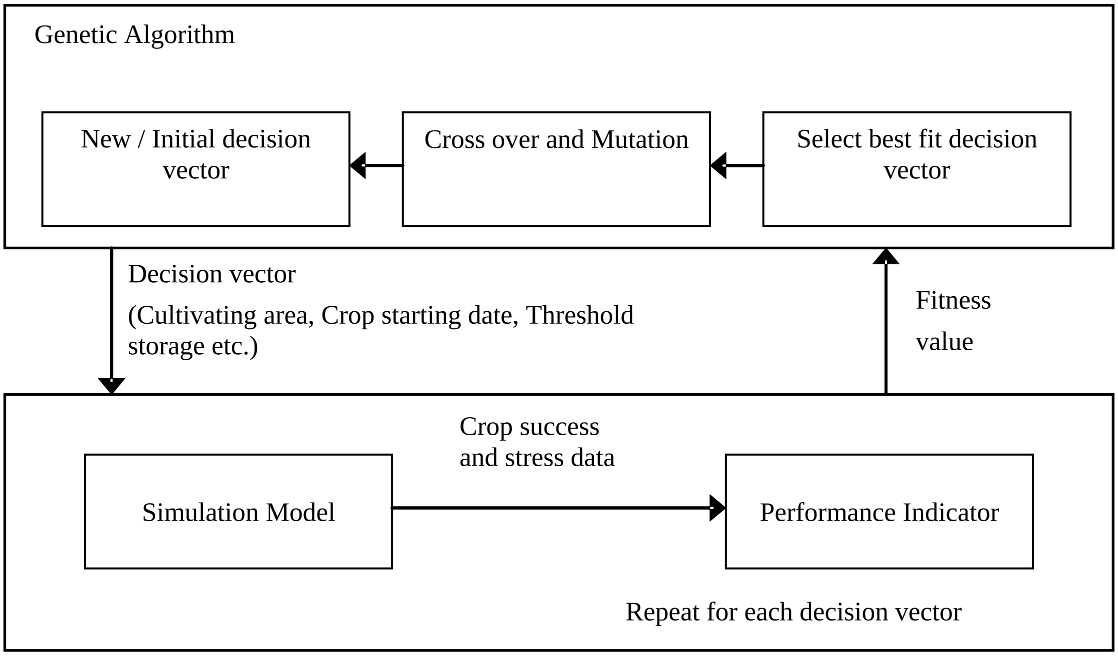

Figure 7.1 Bi-level simulation – optimization model for crop calendar adjustment

7.5 MODEL FORMULATION

Data pertaining to the past 22 years data obtained from Water Resources Organization, Middle Ponnaiyar River division, Public Works Department, Thiruvannamalai. is used for this study. The objective of the model is to maximize the net benefit in terms of economic profit over a period of 22 years, from the paddy crop and groundnut crop in the direct command. The quantity and cost required for pumping the ground water is not considered. The objective function of the model is as follows.

$$Maximize \sum_{i=1}^{n} pp_i.(1-k_1).k_2.a.bc+\sum_{i=1}^{n} pg_i.(1-k_1).(1-k_2).a.bg \qquad (7.1)$$

where pp_i – performance indicator for paddy crop as given below, pg_i – performance indicator for groundnut crop as given below, a – total command area under direct command in million m^2, k_1 – percentage command area to be left uncultivated, k_2 – percentage paddy cultivable area in the total cultivable area, bc – net benefit of paddy crop per million m^2 area, bg - net benefit of groundnut crop per million m^2 area.

$(1 - k_1).a$ – balance command area available for cultivation, $(1 - k_1).k_2.a$ – paddy cultivable command area, $(1 - k_1).(1 - k_2).a$ – Groundnut cultivable command area.

$pp_i = \sum_{i=1}^{n} \frac{(PD_i - PDf_i)}{PD_i}$ where pp_i = Performance Indicator for paddy crop for the period i; PD_i= Water demand for paddy for the period i; PDf_i =Water deficit for paddy for the period i: n = number of periods for paddy crop (140 days at ten days per period). $pg_i = \sum_{i=1}^{n} \frac{\left(GD_i - GDf_i\right)}{GD_i}$ where pg_i = Performance Indicator for groundnut crop for the period i; GD_i= Water demand for groundnut for the period i; GDf_i= Groundnut deficit for the period i: n = number of periods in groundnut crop period (100 days at ten days per period).

The net benefit of paddy crop and groundnut crop per million m^2 area of the crop is worked out after duly deducting all expenses (from starting the cultivation of the crop to marketing the produce) except the cost of ground water. The yield and cost details of the crops in the study area are given below.

Paddy crop:

Yield per million m^2 area = 4, 440,000 N; Market price per N = Rs.1.333;

Total marketable price of paddy produce per million m^2 area = Rs.5, 918,520;

Total expenses (from starting of the crop to marketing the produce) = Rs.3, 323,520;

Net benefit of paddy crop per million m^2 area of cultivation = Rs.2, 595,000.

Groundnut crop:

Yield per million m^2 area = 1, 960,000 N; Market price per N = Rs.1.875;

Total marketable price of groundnut produce per million m^2 area = Rs.3, 675,000;

Total expenses (from starting of the crop to marketing the produce) = Rs.2, 439,000;

Net benefit of groundnut crop per million m^2 area of cultivation = Rs.1, 236,000.

The continuity constraints, minimum and maximum storage capacity constraints are used. Based on the principle of conservation of mass, the continuity equation for the reservoir operation is given by

$$S_{t+1} = S_t + I_t - (R_t + SP_t) - EL_t \tag{7.2}$$

A set of storage capacity constraints are given below.

$$S_{\min} \leq S_t \leq S_{\max} \tag{7.3}$$

where S_t= current available reservoir storage at the start of the period t; S_{t+1} = reservoir storage at the end of the period t, I_t = inflow during the period t; R_t = release during the period t; EL_t = evaporation loss in the reservoir during the period t; SP_t = spill during the period t; $S_{\min}$ = minimum storage and $S_{\max}$ = maximum storage.

The evaporation loss of irrigation water in the Sathanur irrigation system is calculated utilizing the relationship between the storage of the reservoir and the corresponding water spread area ($y = 0.117x$; $R^2 = 0.9339$; y is water spread area in m^2 and x is storage in m^3) and multiplying the water spread area with mean evaporation rate. Taking into account for losses due to seepage and evaporation for the irrigation water in its travel through the canal and distributatories, the efficiency of the canal and distributaries of the Sathanur irrigation system is 66% (PWD, 1993). Fifty percentage of the total rainfall in each period during the paddy crop is considered as effective rainfall in the command area (Allen et al., 1998). Though the dead storage of the reservoir is 9 million m^3, the reservoir is not drained to 9 million m^3. Generally an amount of 33 million m^3 is kept as a reserve for emergency use. Since this is followed like a rule in reservoir operation, the same has also been taken into consideration in the model study. Only during the extreme drought, the storage is drained to 9 million m^3 supplying water only for drinking purpose. The total drinking water supply requirement is 1 million m^3 per period. If the storage in the reservoir is 140 million m^3 or more, a quantity of 34 million m^3 of water is to be released from the reservoir for stabilizing the second crop (paddy) under down stream side Thirukoilur barrage (old command area). This requirement is fulfilled only after satisfying the Sathanur command requirement.

7.6 CROP CALENDAR ADJUSTMENT

In the simulation-optimization model the cost incurred in pumping ground water is not considered and similarly the contribution of rainfall (in million m^3) during the crop period of paddy crop is added with the irrigation release from the reservoir for cultivation of paddy crop.

7.6.1 Simulation-optimization model

In the simulation-optimization model, it is proposed to ascertain the possibility of cultivating the paddy crop from September I period. Options are considered to start the cultivation of paddy crop either in September I period or in the consecutive periods till January III period. Fifteen policies namely policy A, B, C, D, E, F, G, H, I, J, K, L, M, N and O respectively were framed as follows. Policy A allows the start of paddy crop either in September I or II or III period; policy B allows the start of paddy crop either in September II or III or October I period; policy C allows the start of paddy crop either in September III or October I or October II period and so on.

The simulation model selects the appropriate period at which the irrigation release can be made as per the crop water requirement (CWR) of paddy if minimum required threshold storage is available. This appropriate period will be selected using optimization model, which produces maximum net benefit, instead of simulating for all the periods.

The necessary flow chart for the simulation is presented in the Appendix A-6.

In this work, average performance indicators for various supplies like drinking water supply (the primary demand), supply to tank (indirect command), supply to direct command area (for paddy crop) and supply to irrigated dry crop (groundnut) are employed as given below.

$$API = \frac{1}{m}\sum_{i=1}^{n}\frac{(D_i - Df_i)}{D_i} \qquad (7.4)$$

Where API = Average Performance Indicator; D_i=Demand for the period i; Df_i=Deficit for the period i; n = number of periods of supply. The value of 'n' is 36, 6, 14, 10 and 6 for supply to drinking water, supply to tank, irrigation release to paddy crop, irrigation release to groundnut and release to Tirukoillur barrage respectively. Number of years considered in the model, $m = 22$ *Years.*

The overall performance indicator of the Sathanur irrigation system for each year is calculated as below.

$$OPI_j = \frac{\sum_{i=1}^{i=36} TS_i}{\sum_{i=1}^{i=36} TD_i} \qquad (7.5)$$

Where OPI_j = Overall performance indicator for j^{th} year;

TS_i = Total quantity of various supplies; TD_i = Total demand of various requirements.

Overall performance indicator for the Sathanur reservoir system is also calculated per year (36 periods), for 22 years.

7.7 GENETIC ALGORITHM

Sathanur command has multiple constraints and release of water for irrigation is based on certain priority condition. The model has many options like if a paddy crop is present another groundnut crop cannot be cultivated; if threshold storage to start a crop is not available, the check can be made in the next period if suitable etc. These are complex constraints. Even though the objective function is simple non-linear function, these complex constraints available in the model have to be treated as mixed integer LP constraints. If Stochastic Dynamic Programming is used, the ‘curse of dimensionality’ problem usually occurs. Moreover, SDP requires the discretization of state variables and explicit representation of stochasticity in-terms of transition probabilities. To avoid fitting the problem into a rigid framework of other non-linear programming techniques, simulation-genetic algorithm based model is adopted. GA overcomes all the difficulties encountered in other non linear programming. Since there are many constraints like this, this problem is solved using GA.

Using Genetic algorithm (GA), the reservoir operation of Sathanur irrigation system is optimized for the available 22 years of data. The crops considered in the analysis are paddy and groundnut. The possibility of changing the crop calendar of paddy crop is attempted. Since the CWR of paddy is more, it is not possible to fulfill the entire CWR of paddy through irrigation water alone. Further as the crop calendar is being adjusted, effective rainfall contribution is possible. Hence in this analysis effective rainfall contribution is considered. Ground water is used as supplement for paddy cultivation in order to reduce the release from reservoir. In practice, the farmers are extracting the deficit percentage of CWR of paddy through the ground water sources. For maximizing the benefit, five decision variables (k_1 *to* k_5) which are the controlling parameters are optimized. The first decision variable 'k_1' is the percentage command area to be left empty without cultivation. The second decision variable 'k_2' is the percentage area of the land over which paddy can be cultivated. Thus the remaining area in the total command area, (in excess of land area to be left uncultivated and paddy cultivating area), is allocated for groundnut cultivation. The other three decision variables (k_3, k_4 *and* k_5) specify the target storage volume required in the reservoir for starting paddy crop cultivation. The developed simulation-optimization model checks whether the cultivation of paddy crop can be taken up in the first (I) calendar period or in the consecutive second (II) or third (III) calendar period. Out of these three decision variables, the third decision variable 'k_3' belongs to the target storage volume required in the reservoir for releasing water in the first calendar period of paddy crop. In the starting time of first calendar period, if the storage volume in the reservoir is less than that of the third decision variable 'k_3' obtained from optimization, the release from reservoir is not possible and hence paddy crop cannot be started in the first calendar period i.e., September I period. Similarly, the fourth and fifth decision variables (k_4 *and* k_5) specify the target storage volume required in the reservoir for the consecutive second and third calendar period of paddy crop respectively. If the paddy crop cultivation is not started in the I period, then the model checks whether the paddy crop cultivation can be started in the second period provided the actual storage volume available in the reservoir during the second period is equal to or greater than target storage volume obtained from fourth decision variable 'k_4'. If the paddy crop is not started in either of the first or second period, the starting of paddy crop cultivation in the III period is checked if the reservoir storage is equal to the target storage volume specified by the fifth decision variable 'k_5'. If the paddy crop is not started in either I period or II period or III period, then there is no possibility of cultivation of paddy crop in that year. Since GA is dependent on various parameters such as population, generations, cross over and mutation probabilities, various combinations are tried. Several trial runs are carried out by changing the cross over probability from 0.5 to 0.9 with an increment of 0.05. Similarly the mutation probability is varied from 1% to 5% in step of 0.05%. The population size is kept as 200. From the initial trail runs, it is found that 1000 generation is sufficient for getting optimal solution. Hence the maximum generation allowed for each trail run is 1000. Further trail runs are carried out with different random seeds.

7.8 RESULTS AND DISCUSSION

In this case study, the cost required for pumping the ground water has not been taken into account due to free electricity provided to the farmers. For paddy crop, fifty percent (50%) of total rainfall in each period is considered as effective. The optimal result shows that no area of land in the command is to be left uncultivated (barren area) for all the policies as the value of first decision variable 'k_1' is zero. The entire command area should be cultivated for achieving maximum net benefit. Table 2 indicates the description of various policies and their performance indicators values for various demands. The paddy crop can be cultivated in the entire command area (152 million m^2) for getting maximum net benefit from the cultivation of crop. The value of second decision variable 'k_2' is equal to one for policies A, B, C, D, E, F, G, H and I. This indicates that in these policy periods (from September I upto November III periods), the paddy crop can be cultivated in the entire command area. In the remaining six policies viz., J, K, L, M, N and O, the entire command area cannot be cultivated with paddy as the value of 'k_2' is less than one. The minimum area of paddy cultivation is 68% of the total command area when the paddy cultivation is taken up according to the policy O (started in Januray III period). The paddy cultivation area is 89% of the total command area when paddy is cultivated according to the policy J (started in December I period). For other polices viz., K, L, M and N, the paddy cultivating areas have been restricted to 82%, 74%, 69% and 69% of the total command area respectively. These policy periods fall in the post monsoon periods during which rainfall cannot be expected. This reduction in area of paddy cultivation is due to no contribution or lesser contribution of effective rainfall in these post-monsoon periods. Hence, the CWR of paddy crop cannot be fulfilled with irrigation release from the reservoir alone. This leads to water stress to paddy cultivation which results in reduced area of cultivation of paddy in the command. However, according to policies J to O, groundnut crop cultivation can be taken up from December II period for the remaining command area along with the paddy cultivation to enhance the benefit. The groundnut cultivation is possible since the CWR of groundnut is less than that of paddy. In these policies, the performance indicator value for paddy ranges from

0.57 upto 0.55. For policies J, K and L, the performance indicator value for paddy is 0.57. For policies N and O, the value is 0.55 and for policy M the value is 0.56. The performance indicator value for groundnut ranges from 0.64 upto 0.79. Further analysis clearly shows that the Sathanur irrigation system can perform efficiently if the groundnut crop is cultivated in the entire command area.

From the results of optimization it is found that policy D (starting the cultivation of paddy crop in the first period of October) provides the maximum net benefit. The best operating policy D results in paddy cultivation for 20 years out of 22 years. Due to poor storage in the reservoir owing to the monsoon failure, the policy skips cultivation of paddy crop for two years (8th and 20th year). Out of the 20 years, the value of paddy performance indicator is more than 0.5 for 17 years. For 3 years the paddy performance indicator value ranges between 0.15 and 0.45. The paddy performance indicator values are 0.45, 0.26 and 0.15 for the 3rd, 7th and 21st years respectively since the annual rainfall during these 3rd, 7th and 21st years is well below the average annual rainfall of the command area. During these 3rd, 7th and 21st years, for all policies, the paddy performance indicator values range between 0.1 and 0.4. The CWR of paddy for the entire command area is 187.0129 million m^3 per year and for the 20 years period, the total quantity of CWR of paddy crop works out to be 3740.258 million m^3. In this best crop calendar period, the effective rainfall contribution in the crop period for paddy is 523 million m^3. The total water use (including rainfall contribution) by the paddy in the 20 years period works out to be 2901.068 million m^3. The paddy is under water stress for a quantity of about 839.19 million m^3. Out of the total quantity of 3740.258 million m^3, the effective rainfall contribution is 13.98%. Apart from the effective rainfall contribution, the irrigation release for the entire command is worked out to be 63.58% of the total quantity of CWR of paddy. The remaining quantity of water (839.19 million m^3) is extracted from the ground water source. The ground water contribution is about 22.44% of total quantity of CWR of paddy. This clearly shows that the water available in the Sathanur reservoir system cannot meet out the CWR of paddy.

The performance of the paddy crop in 20 years, when the crop cultivation is started in different policies (calendar periods - from the first period of September month (September I) through the third period of January month (January III)) is shown in figure 7.2. The figure 7.3 shows the performance indicator values for 22 years for other releases namely drinking water supply, release to tank demand, release to down stream side Thirukoilur barrage and irrigation release to groundnut crop if the groundnut is cultivated from the second period of December month (December II). The drinking water requirement from the reservoir is 1 million m^3 per period (for 10 days). In the simulation optimization programme, simulation for other demands (based on priority) viz., the tank demand, paddy crop demand and down stream Thirukoilur barrage requirement (old command demand) are performed only after fully meeting out the drinking water demand (1 million m^3/period). Hence the performance indicator of drinking water demand is independent from the releases to other demands. Thus, any increase or decrease in the performance measures of other three policies has no effect on performance indicator of drinking water supply demand. Hence the performance indicators for various releases are not interdependent. The figure 7.4 indicates the optimum net benefit of paddy cultivation, irrigation release from the reservoir and effective rainfall contribution over 20 years (out of 22 years) with different policies (different crop starting periods). The maximum net benefit for 20 years is Rs.6118.82 Million from the cultivation of paddy in the entire command of the Sathanur irrigation system. The maximum fitness function value of Rs.6118.82 Million is achieved for crossover probability value of 0.8 and mutation probability value of 0.03. Termination criterion is set to perform 1000 generations of GA simulation. Even before reaching 1000 generations, maximum fitness function value is reached at 915th generation, which is taken as solution for the present study. The optimized decision variables that maximize the net benefit, after a number of iterations are 0, 1, 0.13, 0.07 and 0.8. In the best policy period D (October I), the performance indicator value for various releases viz., release to drinking water, release to tank, release to paddy crop, release to groundnut if required and release to down stream side Thirukoilur barrage are 0.97, 0.63, 0.71, 0, 0.55 respectively. Since entire command area is cultivated with paddy, the performance indicator for release to groundnut is zero. The first priority of supplying drinking water to Thiruvannamalai town and nearby villages is almost fulfilled. About 63% of the water requirement for filling up the 90 tanks (both in LBC and RBC) of the Sathanur system is possible. The remaining 37% of the tank requirement can be filled up from the rainfall and runoff from their own catchment. Eighteen years out of 22 years had a good rainfall during the crop period of the paddy (between second period and seventh period of paddy crop). The deficiency in the supply of water to paddy crop can be managed with the ground water source.

The model also indicates that the paddy crop cultivation can be started in the first period of October month (October I) for 19 years out of 20 years. In one year (21st year) the paddy cultivation is started in the second period of October month (October II) due to the poor storage in the reservoir in the first period of October. In this year, the paddy crop cultivation is started in the second period of October as the required target storage is available in the reservoir in the second period of October and the rainfall contribution is also available from the second period of October month. The average value of the overall performance indicator was found out to be 70%. Table 7.3 shows the demand for paddy crop, the irrigation release from the reservoir and the effective rainfall contribution for paddy. The deficit water which arises due to paddy cultivation is extracted from ground water source.

Table 7.2 Description of various policies and performance indicator values for various demands

Sl. No.	Name of policy	Description of policy						Net benefit (in Million Rupees)	Average performance indicator (*API*) for various supplies (equation 7.4)				
		Crop starting period for the decision variable **“ k_3”**	k_1	k_2	k_3	k_4	k_5		Drinking water	Tank	Paddy	Groundnut	Thirukoilur barrage
1.	Policy A	Sep. I	0	1.00	0.08	0.09	0.06*	5416.65	0.98	0.64	0.62	0	0.55
2.	Policy B	Sep. II	0	1.00	0.06	0.17	0.18*	5975.83	0.98	0.64	0.69	0	0.55
3.	Policy C	Sep. III	0	1.00	0.13	0.17	0.13*	5692.84	0.97	0.63	0.66	0	0.59
4.	Policy D	Oct. I	0	1.00	0.13	0.07	0.80*	6118.82	0.97	0.63	0.71	0	0.55
5.	Policy E	Oct. II	0	1.00	0.13	0.25*	0.19*	5929.79	0.97	0.62	0.68	0	0.55
6.	Policy F	Oct. III	0	1.00	0.13	0.15*	0.21*	5634.88	0.96	0.63	0.65	0	0.59
7.	Policy G	Nov. I	0	1.00	0.21	0.18	0.68*	5365.20	0.97	0.63	0.62	0	0.59
8.	Policy H	Nov. II	0	1.00	0.13	0.23*	0.97*	5126.78	0.97	0.64	0.59	0	0.59
9.	Policy I	Nov. III	0	1.00	0.17	0.69*	0.55*	4967.17	0.96	0.66	0.57	0	0.59
10.	Policy J	Dec. I	0	0.89	0.10	0.55	0.96*	4738.21	0.97	0.69	0.57	0.64	0.59
11.	Policy K	Dec. II	0	0.82	0.05	0.68*	0.40*	4521.42	0.98	0.71	0.57	0.67	0.64
12.	Policy L	Dec. III	0	0.74	0.07	0.05*	0.82*	4409.41	0.97	0.72	0.57	0.71	0.64
13.	Policy M	Jan. I	0	0.69	0.30	0.74*	0.14*	4327.40	0.98	0.73	0.56	0.75	0.64
14.	Policy N	Jan. II	0	0.69	0.23	0.74*	0.27*	4279.62	0.98	0.75	0.55	0.78	0.64
15.	Policy O	Jan. III	0	0.68	0.18	0.05	0.52*	4266.74	0.98	0.75	0.55	0.79	0.64

* indicates the insensitive decision variable

Contd…

Table 7.2 Description of various policies and performance indicator values for various demands

\# ***k_1*** *= Proportion of cultivable area to be left uncultivated.*
k_2 *=Proportion of paddy cultivable area.*
***k_3* =** *Proportion of target storage limit in the first crop starting period*
***k_4* =** *Proportion of target storage limit in the successive second starting period*
***k_5* =** *Proportion of target storage limit in the successive third starting period*

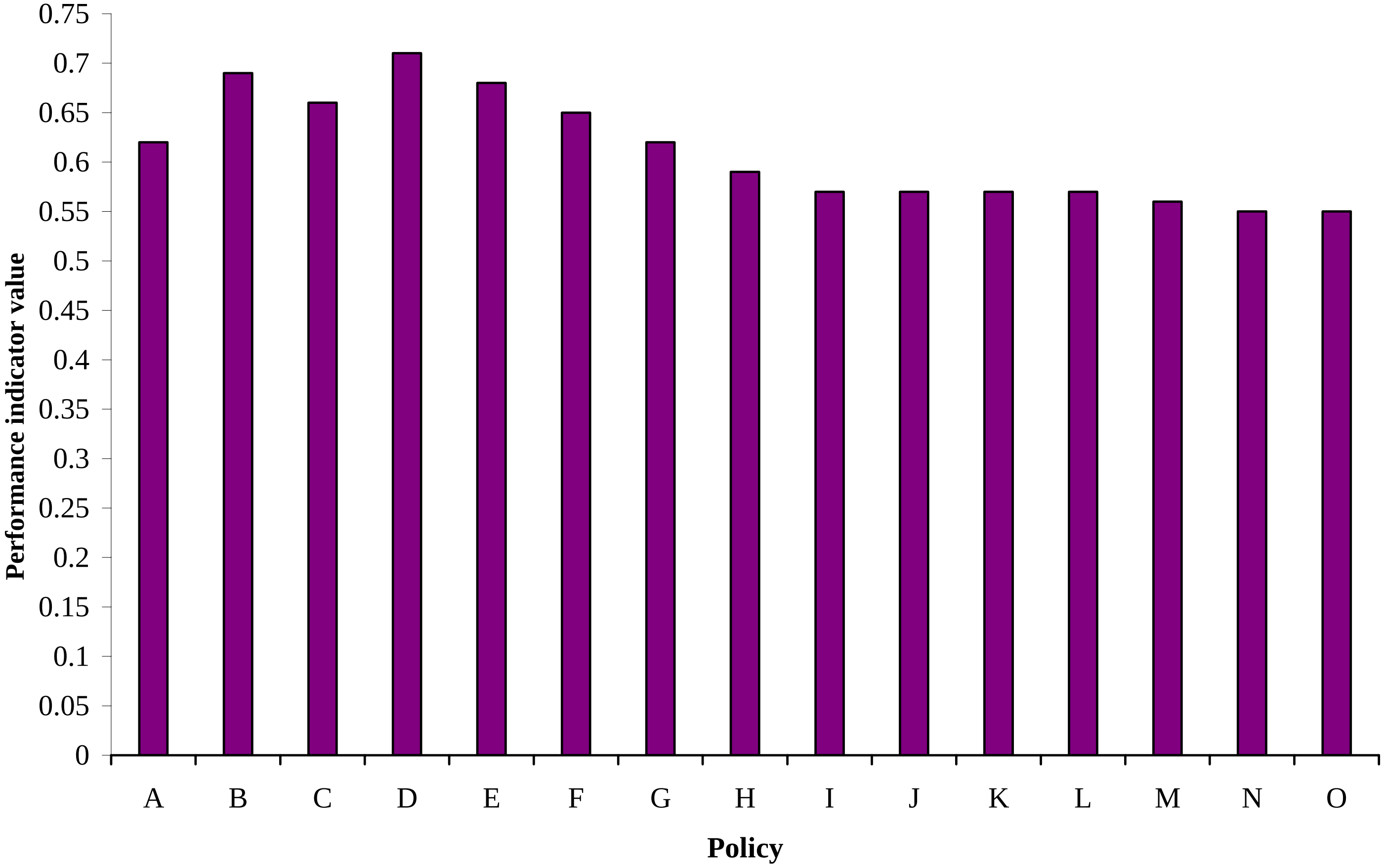

Figure 7.2 Performance indicator value for paddy crop for 20 years in different policies

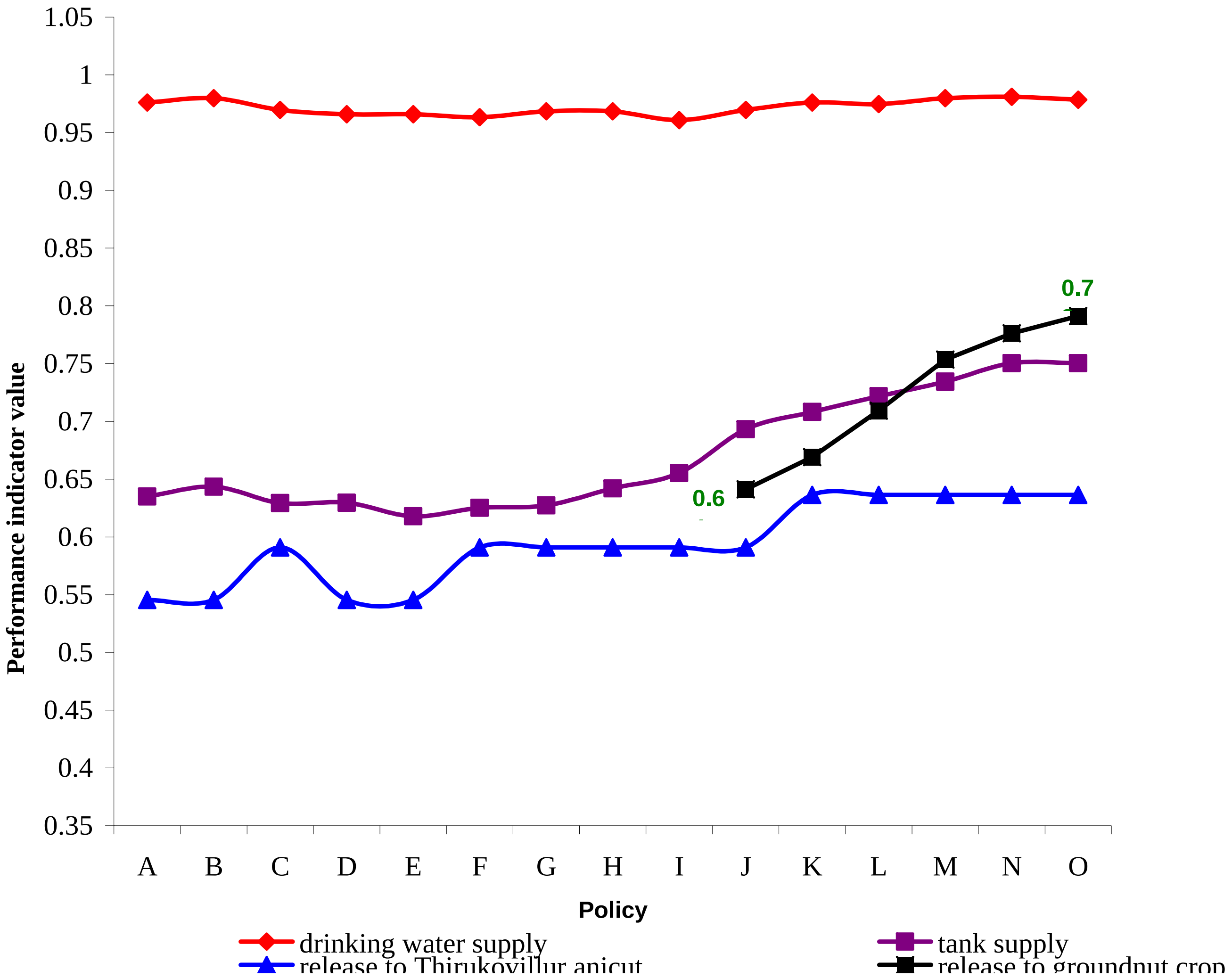

Figure7.3 Performance indicator value for other releases for 22 years in different policies

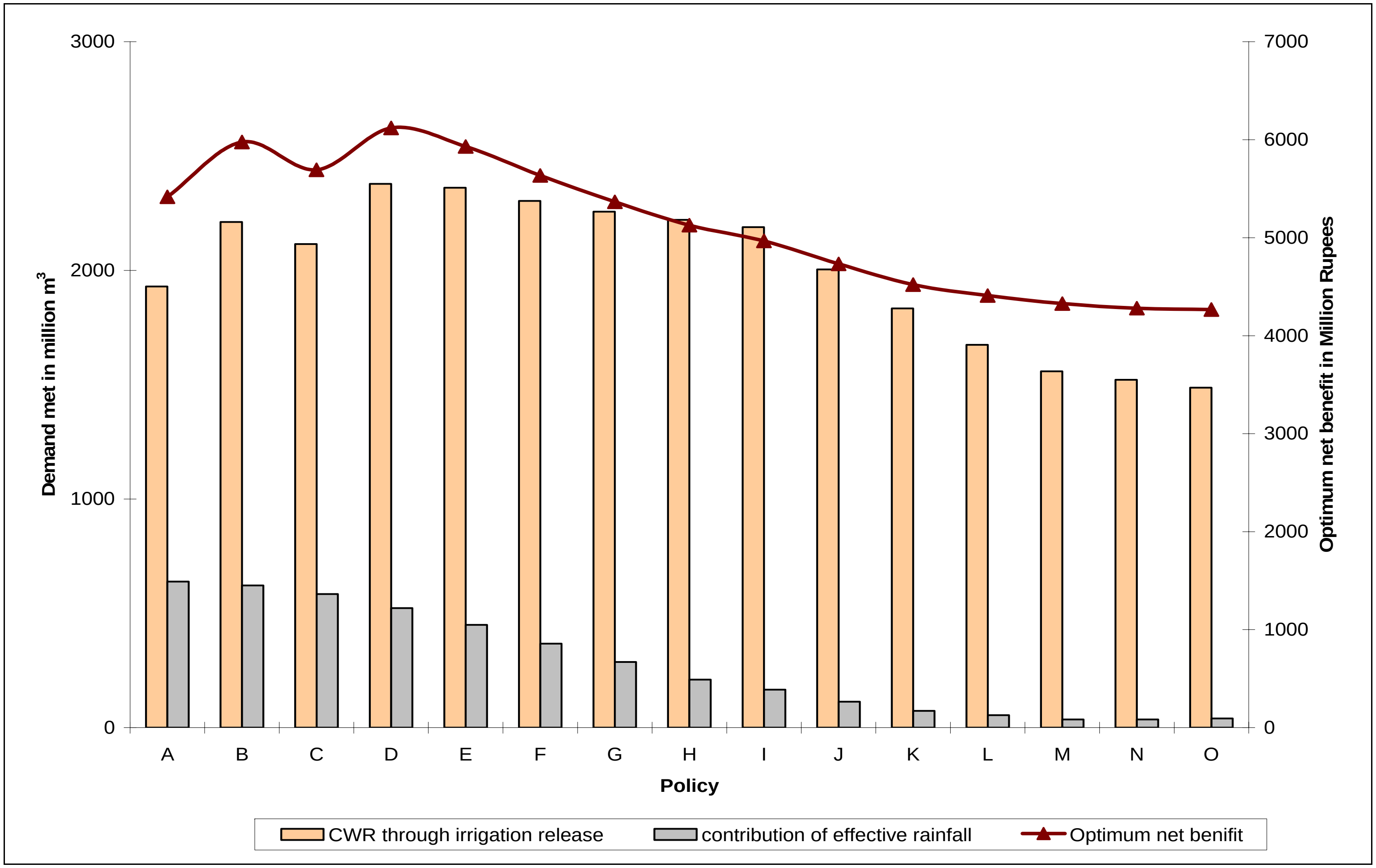

Figure 7.4 Net benefits of paddy crop, Irrigation release and Contribution of effective rainfall for 20 years in different policies.

Table 7.3 Demand and Demand met of CWR of paddy crop for various policies

Sl. No.	Name of policy	Nos. of successful years out of 22 years	Total demand of CWR of paddy in million m^3	Demand met in CWR of paddy crop in million m^3		
				Through irrigation release	Contribution of effective rainfall	Deficit / through ground water source
1.	Policy A	18	3366.233	1929.156	639	798.077
2.	Policy B	18	3366.233	2211.276	622	532.957
3.	Policy C	18	3366.233	2115.104	584	667.129
4.	Policy D	20	3740.258	2378.068	523	839.19
5.	Policy E	20	3740.258	2361.448	450	928.81
6.	Policy F	20	3740.258	2303.622	368	1068.636
7.	Policy G	20	3740.258	2256.760	287	1196.498
8.	Policy H	20	3740.258	2220.722	210	1309.536
9.	Policy I	20	3740.258	2189.046	166	1385.212
10.	Policy J	19	3162.388	2004.225	114	1044.163
11.	Policy K	20	3067.010	1833.712	74	1159.298
12.	Policy L	20	2767.790	1674.222	55	1038.568
13.	Policy M	18	2322.700	1557.984	36	728.716
14.	Policy N	18	2322.700	1521.482	36	765.218
15.	Policy O	19	2416.207	1486.767	40	889.440

7.9 CONCLUSION

Any reservoir operation policy for irrigation system should be designed to benefit the farmers. The change in farmer's attitude needs to be taken into account while revising the existing practice. The present operating rules in the Sathanur irrigation system is based on engineering judgment and experience. This operating rule needs to be modified to suit the requirement of existing cultivation needs and practices of the farmers. The simulation-optimization model that has been formulated by the study and applied to the system clearly establishes that the reservoir release to direct command for irrigation water supply to paddy crop can be started in the first period of October (October I) (policy D) instead of the usual second period of December (December II). From the analysis, it is found that 22.44% of the CWR of paddy crop should be extracted from the ground water source if the policy D is practised for paddy cultivation. For achieving maximum net benefit and better performance without any water stress, the ground water source should be conjunctively used with irrigation release. In this study, the paddy crop used is the same crop being cultivated in the command area. However, short duration paddy variety and modern irrigation practice like wet and dry farming may further reduce the irrigation water requirement and dependence on the ground water.