CHAPTER 6: HEDGING RULE BASED SIMULATION STUDY

6.1 INTRODUCTION

The most common reservoir operation policy implemented in practice is a Standard Operating Policy (SOP). SOP releases water as closely as possible to the demand target, saving only surplus water for future demand. During the periods of operation, when the inflow is plentiful, SOP is practical. However in the later period of operation, SOP does not consider the potential shortage vulnerability. Due to uncertain future inflows and nonlinear economic benefits for released water, the simple choice of releasing the water or storing the water for future use becomes highly complex (Shih and Revelle, 1994 and 1995). The complexity of how much water to be withheld from the immediate release made, and retaining that water in storage, is called “hedging” (Bower et al., 1962). Hedging rules for reservoir operations can be represented in different ways. For example, the total available water which consists of reservoir storage plus inflow can be used as a prompt to start hedging (Bayazit and Unal, 1990; Srinivasan and Philipose, 1998). In many cases, only the reservoir storage is used as a trigger for operating rules (Houck et al., 1980; Neelakantan and Pundarikanthan, 1999, 2000).

Hedging rules curtail releases over some range of water supply to retain water in storage for use in later periods. Thus, some water is stored, rather than released, even when there is enough water for full release requirement in the present period. If the reservoir has low refill potentials or uncertain inflows, then hedging provides insurance for the most valued water uses. The intent of hedging is to reduce the water shortage and cost of large shortage at the drought period, by way of sacrificing more frequent small shortage. Neelakantan and Pundarikanthan (1999) developed a simulation-optimization methodology for optimizing the multiple hedging rules for the operation of drinking water reservoir, by linking the simulation model to the optimization model. In this, management decision variables are passed from the optimization to the simulation model to obtain the value of the objective function. Neural network model is developed for the simulation of the reservoir system operation for enhancing the speed of optimization process. Tu et al. (2003) developed a guideline for reservoir release using mixed integer linear programming model that considers both rule curves and hedging rules. Draper and Lund (2004) demonstrated that the optimal hedging policy for water supply reservoir operation depends on a balance between beneficial release and carryover storage values. You and Cai (2008 a&b) described a method for integrating hedging policy with stochastic simulation processes for reservoir operations.

Sathanur reservoir is a multipurpose reservoir and its prime objective is supplying drinking water to the Thiruvannamalai town. The other priority preferences taken in order are supplying irrigation water to indirect command (through tank), to old command (according to the riparian rights of the area) and to new demand (groundnut demand). In the present study, a hedging rule for Sathanur irrigation system is developed. Since the water required for fulfilling the primary requirement is retained in the reservoir as reserve stock for potential future use, the variations in the performance indicator of other releases are examined.

6.2 THE PRESENT SCENARIO

The LBC and RBC are opened for irrigation simultaneously between December and April. The direct command (15200 ha) gets irrigation for groundnut, an ID crop and indirect command (tank command – 3020 ha) get water for paddy (wet crop) in three spells in September, December, January and February, for providing supplemental irrigation for paddy crop. The direct command will not receive its supply, whenever there is supply to tanks. In the present condition, there is no rainfall contribution during the crop growth as the crops are started after the rainfall season. In the present study, time discretization to be adopted is same as given in the section 5.3.

Table 6.1 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
01	Drinking water demand	1	Refer table 3.4		
02	Tank demand (indirect command)	2	Refer table 3.4		
03	Irrigated dry crop (new command) demand	3	Average 6.35	From II period of December to II period of March	Ten periods
04	Old command demand	4	Refer table 3.4		
05	Proposed diversion demand (S) (new demand)	5	**S**	I, II & III periods in October & November	Six periods (To be assessed through model)

The value of **'S'** is taken from {5, 10, 15, 20} million m^3. Priority 1 is the top priority and priority 5 is the least priority.

6.3 PROBLEM DEFINITION

The average annual inflow is about 314.08 million m^3 and number of fillings per year works about 1.4 over the period of 22 years considered in the analysis. The average total annual demand from the system is about 228.82 million m^3. Table 6.1 presents different demands and their priorities in the reservoir system. Among different supplies, drinking water supply is given top priority. However, the release data from the system reveals that drinking water supply is facing problem during the months of April, May and June. To overcome the shortage in supply for drinking purpose, it is contemplated to reserve enough water in the reservoir for future drinking use before fulfilling the present needs of the other demands. In this research, two cases of simulation models are developed as detailed below.

6.3.1 Case I

In the first case, the drinking water quantity required for certain number of periods (*N)* is reserved as stock for future use. The drinking water required for 3 periods (one month), 6 periods (two months), 9 periods (three months), 12 periods (four months) and 15 periods (five months) is kept as reserve storage (RS_t) in the reservoir and the performance of the system is analyzed. In other words, simulations analyses were conducted for N = 3, 6, 9, 12 and 15 periods. The drinking water demand per period (DD_t) is 1 million m^3. However, for N = 3, an amount of 3.3 million m^3 is reserved. The excess quantity, over 3 million m^3 is considered for accommodating evaporation loss. This excess water is estimated based on the quantity of evaporation at the water spread area of the reserve storage during the reserve duration. For N = 3, 6, 9, 12 and 15 periods, the excess-water quantities, accounting for evaporation loss, are 0.3 million m^3, 0.6 million m^3, 0.85 million m^3, 1.14 million $m^3$and 1.42 million m^3 respectively. The corresponding hedging rule is presented in the flow chart shown in figure 6.2.

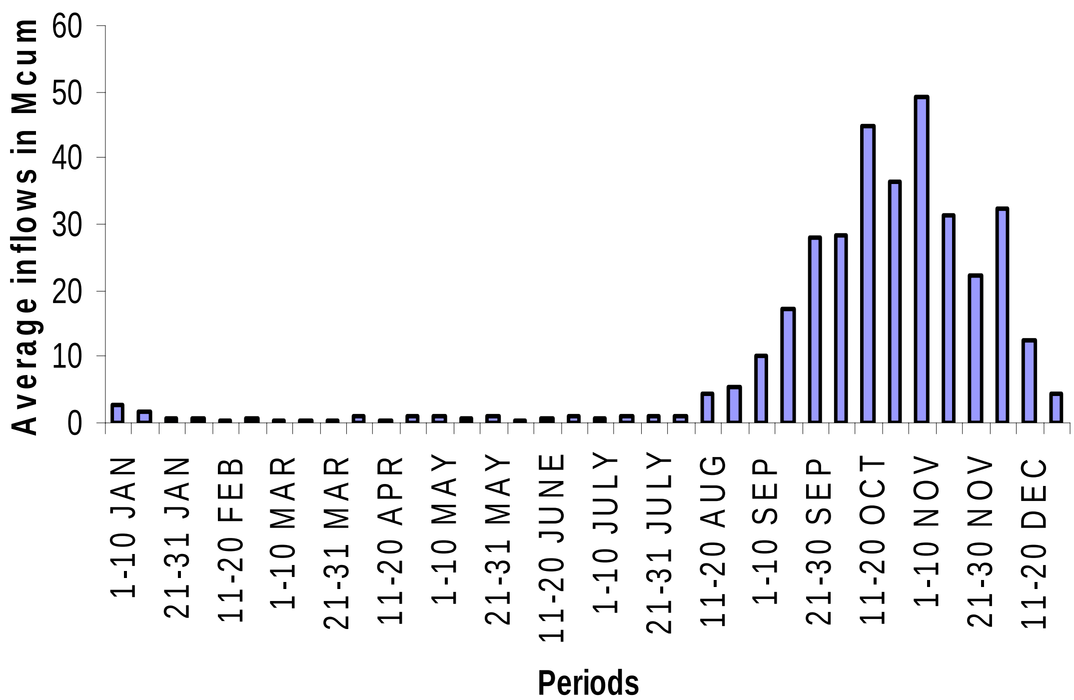

Figure 6.1 Period wise average inflow (1983 - 2005)

6.3.2 Case II

Further, the data also reveals that during the rainy season in October and November, inflow is copious and many years experienced spills from the reservoir. The period wise average inflow for 22 years is given in figure 6.1. This copious water is let out of the reservoir as spill water after achieving the full capacity of the reservoir. Since the crops are started only after the monsoon season in the Sathanur command, the excess water cannot be used for irrigation. Hence, an attempt is made to divert this spill or additional water (new demand) to nearby Chiyaru river basin through trans-basin canal. Hence, in the second case, a simulation analysis is performed on diverting a sizeable quantity (*S*) of water to other river basin in addition to reserving water for drinking purpose (as in the Case I).

In this second case, simulations are performed to divert a sizable quantity (*S*) during the October and November after retaining the reserve storage of water for certain periods for drinking purpose viz., 3, 6, 9, 12 and 15 periods. Different diversion quantities viz., 5 million m^3, 10 million m^3, 15 million m^3 and 20 million m^3 of water per period are considered. With these diversion quantities, simulation analysis is performed with each reserve storage quantity. The possibility of diversion of water to the other basin in each case is checked with varied percentage of empty storage requirement (U) from the live storage of the reservoir. The value of (U) is 10% (10% of 207 million m^3 = 20.7 million m^3), 15% and 20% of live storage capacity of the reservoir. Three available options are; (1) The reserve storage requirement (RS_t) for future drinking water needs; (2) diversion quantity (S) and (3) the empty storage requirement in the reservoir (U). RS_t is taken from {3, 6, 9, 12, 16 periods of drinking water requirement}; S is taken from {5, 15, 20 million m^3} and U is taken from {10%, 15% and 20% of empty storage capacity from live storage capacity}. Simulations are performed with all possible combination of reserve storage requirement (RS_t), new demand (S) and empty storage requirement in the reservoir (U). The best combination is obtained from the results of simulation.

6.4 FLOW CONTINUITY EQUATION

Based on the principle of conservation of mass, the continuity equation for the reservoir operation is given by

$$S_{t+1} = S_t + I_t - (R_t + SP_t) - EL_t \tag{6.1}$$

$$S_{\min} \le S_t \le S_{\max} \tag{6.2}$$

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 total release of water from reservoir (R_t) needs to be made according to the priorities. The required quantity for various priorities is mentioned in table 6.1. This can be written mathematically as follows.

$$R_t = RD_t + \sum_{i=1}^{3} R_{i,t} \qquad (6.3)$$

Where

RD_t = Supply to the drinking water demand during the period, t

$R_{1,t}$ = Release to the tank (indirect command) during the period, t

$R_{2,t}$ = Release to the irrigated dry crop (groundnut) (direct command) during the period, t

$R_{3,t}$ =. Release to the old command area during the period, t.

The Evaporation loss of irrigation water in the Sathanur irrigation system is calculated by drawing a plot, between the storage of the reservoir and the water spread area and a polynomial linear equation $y = 0.117x$ is obtained for the curve with $R^2 = 0.9339$ where y is water spread area in m^2 and x is storage in m^3. The efficiency of the canal and distributaries of the Sathanur irrigation system is assumed as 66% taking into account for losses due to seepage and evaporation for the irrigation water in its travel through the canal and distributories (PWD, 1993). To meet out the drinking water supply requirement of the colonies in Thiruvannamalai town located 32 km from dam site and the nearby villages, 1 million m^3 of water per period from the Sathanur reservoir is used. The monthly average evapotranspiration of a reference crop (ET_o) was estimated using CROPWAT software (FAO, 1992). Meteorological data from in the Sathanur command was collected for the period of 1982 – 2005 and used in the estimation of crop water requirement. The effective rainfall value considered is 70% of the average seasonal rainfall (Dastane, 1974). The equation 6.1 represents the total release of water from the reservoir during the period t with priority preference. The primary demand (I priority) is achieved by adopting hedging rule for other demands viz., tank demand, ID crop demand and old command demand. The simulation is formulated in such a way that the release is made as per the priority order given in the table 6.1. That is, release to the III priority (release to ID crop) is possible only after fulfilling the second priority (release to tank demand). The fourth priority (old command demand) is fulfilled only after fulfilling the requirements of I, II and III priorities. Hence, assigning of weightage factor is not considered.

6.5 PERFORMANCE INDICATOR

In this work, performance indicator values for various supplies like drinking water supply (the primary demand), supply to tank (indirect command), supply to old command area and supply irrigated dry crop (groundnut) (direct command) are employed.

$$PI = \frac{1}{n}\left[\sum_{i=1}^{o}\frac{SD_i}{DD_i}\right], PI = \frac{1}{n}\left[\sum_{i=1}^{r}\frac{ST_i}{DT_i}\right], PI = \frac{1}{n}\left[\sum_{i=1}^{s}\frac{SG_i}{DG_i}\right] \text{and } PI = \frac{1}{n}\left[\sum_{i=1}^{t}\frac{SC_i}{DC_i}\right] \quad (6.4)$$

Where PI =Performance Indicator; SD_i= Supply to drinking water demand for the period i; DD_i = drinking water demand for the period i; ST_i = Supply to tank demand for the period i; DT_i = Tank demand for the period i; SG_i = Supply to groundnut for the period i; DG_i = Groundnut demand for the period i: SC_i = Supply to old command area for the period i; DC_i = Old command area demand for the period i ;'*n*' is (in years) varies from 1 to 22. '*o*' is (in periods) varies from 1 to 36; '*r*' is (in periods) varies from 1 to 6; '*s*' is (in periods) varies from 1 to 10; '*t*' is (in periods) varies from 1 to 6;

$$Overall\ performance\ indicator\ value\ for\ each\ year = \frac{\sum_{i=1}^{i=36} TSM_i}{\sum_{i=1}^{i=36} TD_i} \quad (6.5)$$

Where TSM_i = Total supply made in ith period; TD_i = Total demand in ith period.

Overall performance indicator value for the Sathanur reservoir system is also calculated per year (36 periods), for 22 years. The average value of the overall performance indicator is about 70%. The Gross Irrigation Requirement (GIR) for groundnut (ID crop) is calculated, as given in table 5.3.

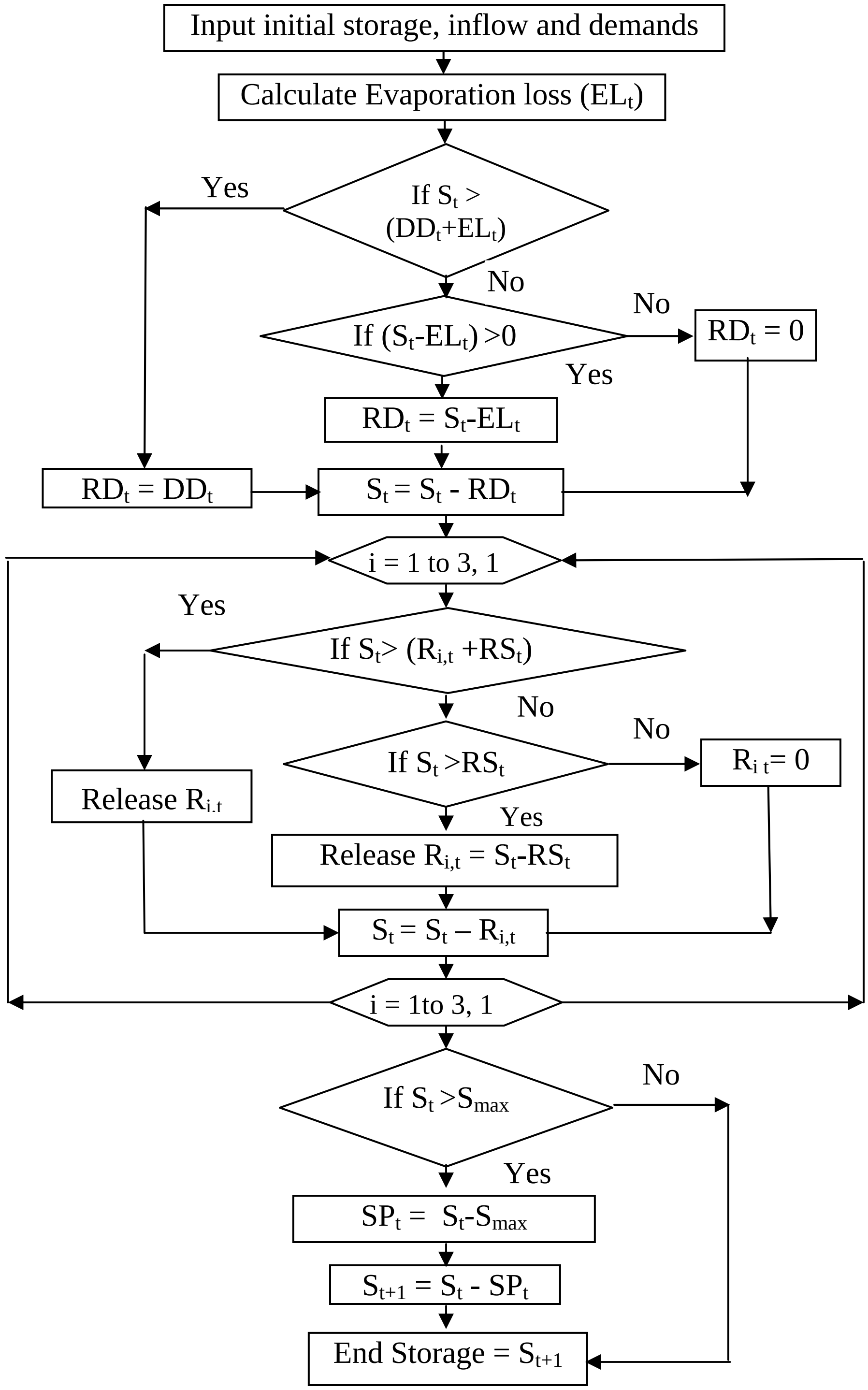

Figure 6.2 Flow chart showing the simulation process

In the flow chart above, 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; EL_t = Evaporation loss in the reservoir during the period t; DD_t = Drinking water demand during the period t; RD_t = Supply to the drinking water demand during the period t; RS_t = Reserve stock quantity of drinking water with evapouration loss quantity in the reservoir during the period t; $R_{1\ t}$ = Release of water to tanks: $R_{2\ t}$ = Release to old command area and $R_{3\ t}$ = Release of water for groundnut crop for the period *t;* S_{mas} = Maximum storage capacity of the reservoir.

6.6 RESULTS AND DISCUSSION

Table 6.2 presents the performance indicator values for various supplies without inter basin water transfer (Case I). The performance does not differ significantly between the simulations with storage reserve of 15-periods and simulation with 3-periods storage reserve. In 15-periods reserve, the total spill in 22 years is 2969.65 million m^3. This spill quantity is about 36 million m^3 more than the total spill in 3-periods reserve. The performance indicator value for drinking water supply is varying from 0.89 to 0.97. About 80% requirement of the tank demand can be met with the release from the reservoir. The remaining 20% required for the tank may be fulfilled from its own catchment area. The value of performance indicator for the tank supply varies from 0.82 to 0.84. The fourth priority i.e., supply of water to old command area suffers a deficit of about 45%. This reduction in the value of performance indicator is due to the coincidence of water requirement periods for the old command with that of the second priority (tank supply). The performance indicator for the supply of water to old command is ranging from 0.55 to 0.58. About 74% of the irrigation requirement of groundnut (ID crop) is fulfilled as the value of performance indicator for the issue of water to groundnut varies from 0.73 in 15-period reserve to 0.75 in 3-period reserve. Here again the farmers are making use of the available ground water for the balance water requirement of groundnut. The variation of the performance indicator value for various supplies from 15- period reserve to 3-period reserve is very minimal and hence the water requirement for drinking purpose for 15-period can be kept as reserve stock in the reservoir for ensuring the regular supply of drinking water without any hiccups.

Tables 6.3, 6.4, 6.5, 6.6 and 6.7 show the performance indicator values for various supplies at different values of empty storage capacity requirement conditions with release to inter-basin transfer (new demand)(S) (Case II).

Table 6.2 Performance indicator values for various supplies (Case I)

Sl. No.	Reserve stock of drinking water with evaporation loss (in number of periods)	Total Spill for 22 years (in million m^3)	Performance indicator values for various releases			
			Release to Drinking water	Release to Tank (indirect command)	Release to Groundnut (ID) crop	Supply to old command
1.	15	2969.65	0.97	0.82	0.73	0.55
2.	12	2964.34	0.97	0.83	0.74	0.55
3.	9	2948.86	0.95	0.84	0.75	0.56
4.	6	2939.95	0.93	0.84	0.75	0.57
5.	3	2932.88	0.89	0.84	0.75	0.58

Table 6.3 Performance indicator values with 3-period reserve (case II)

Sl. No.	Empty storage requirement (in %)	Proposed diversion quantity of flow (S) (new demand) in million m^3															
		5				10				15				20			
		Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies			
		*a	b	c	d	*a	b	c	d	*a	b	c	d	*a	b	c	d
1.	10	0.89	0.84	0.74	0.56	0.89	0.84	0.75	0.56	0.89	0.84	0.74	0.56	0.89	0.84	0.74	0.56
2.	15	0.89	0.84	0.73	0.55	0.89	0.84	0.74	0.55	0.89	0.84	0.73	0.55	0.89	0.84	0.73	0.55
3.	20	0.89	0.84	0.73	0.55	0.89	0.84	0.74	0.55	0.89	0.84	0.73	0.54	0.89	0.84	0.73	0.54

* a = Performance indicator values for drinking water supply.
b = Performance indicator values for the supply to tank (indirect command).
c = Performance indicator values for the supply to groundnut.
d = Performance indicator values for the supply to old command area.

Table 6.4 Performance indicator values with 6-period reserve (case II)

Sl. No.	Empty storage requirement (in %)	Proposed diversion quantity of flow (S) (new demand) in million m^3															
		5				10				15				20			
		Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies			
		*a	b	c	d	*a	b	c	d	*a	b	c	d	*a	b	c	d
1.	10	0.93	0.84	0.73	0.55	0.89	0.84	0.74	0.56	0.94	0.83	0.74	0.55	0.92	0.84	0.73	0.54
2.	15	0.93	0.84	0.73	0.54	0.93	0.84	0.73	0.54	0.94	0.83	0.74	0.54	0.92	0.84	0.73	0.54
3.	20	0.93	0.84	0.73	0.54	0.93	0.84	0.73	0.53	0.94	0.83	0.73	0.54	0.92	0.84	0.72	0.53

* a = Performance indicator values for drinking water supply.
b = Performance indicator values for the supply to tank (indirect command).
c = Performance indicator values for the supply to groundnut.
d = Performance indicator values for the supply to old command area.

Table 6.5 Performance indicator values with 9-period reserve (case II)

Sl. No	Empty storage requirement (in %)	Proposed diversion quantity of flow (S) (new demand) in million m^3															
		5				10				15				20			
		Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies i				Performance indicator values for various supplies			
		*a	b	c	d	*a	b	c	d	*a	b	c	d	nluin	b	c	d
1.	10	0.95	0.84	0.73	0.54	0.95	0.84	0.74	0.54	0.95	0.84	0.73	0.54	0.95	0.84	0.73	0.54
2.	15	0.95	0.84	0.72	0.53	0.95	0.84	0.72	0.53	0.95	0.84	0.72	0.53	0.94	0.84	0.73	0.53
3.	20	0.95	0.84	0.72	0.53	0.95	0.84	0.73	0.53	0.94	0.84	0.72	0.52	0.93	0.84	0.73	0.52

* a = Performance indicator values for drinking water supply.
b = Performance indicator values for the supply to tank (indirect command).
c = Performance indicator values for the supply to groundnut.
d = Performance indicator values for the supply to old command area.

Table 6.6 Performance indicator values with 12-period reserve (case II)

Sl. No	Empty storage requirement (in %)	Proposed diversion quantity of flow (S) (new demand) in million m^3															
		5				10				15				20			
		Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator for values various supplies			
		*a	b	c	d	*a	b	c	d	*a	b	c	d	*a	b	c	d
1.	10	0.97	0.83	0.71	0.52	0.97	0.83	0.71	0.49	0.97	0.83	0.70	0.50	0.97	0.83	0.71	0.49
2.	15	0.97	0.83	0.71	0.51	0.97	0.83	0.70	0.48	0.97	0.83	0.70	0.49	0.97	0.83	0.70	0.48
3.	20	0.97	0.83	0.71	0.51	0.97	0.83	0.70	0.48	0.98	0.83	0.69	0.49	0.97	0.83	0.70	0.48

* a = Performance indicator values for drinking water supply.
b = Performance indicator values for the supply to tank (indirect command).
c = Performance indicator values for the supply to groundnut.
d = Performance indicator values for the supply to old command area.

Table 6.7 Performance indicator values with 15-period reserve (case II)

Sl. No.	Empty storage require-ment (in %)	Proposed diversion quantity of flow (S) (new demand) in million m^3															
		5				10				15				20			
		Performance indicator values for various supplies				Performance indicator values for various supplies				Performance indicator value for various supplies				Performance indicator value for various supplies			
		*a	b	c	d	*a	b	c	d	*a	b	c	d	*a	b	c	d
1.	10	0.97	0.82	0.72	0.53	0.97	0.82	0.71	0.53	0.96	0.82	0.72	0.53	0.97	0.82	0.71	0.53
2.	15	0.97	0.82	0.71	0.52	0.97	0.82	0.71	0.52	0.96	0.82	0.71	0.52	0.97	0.82	0.71	0.52
3.	20	0.97	0.82	0.71	0.52	0.97	0.82	0.70	0.52	0.96	0.82	0.70	0.51	0.97	0.82	0.70	0.52

* a = Performance indicator values for drinking water supply.
b = Performance indicator values for the supply to tank (indirect command).
c = Performance indicator values for the supply to groundnut.
d = Performance indicator values for the supply to old command area.

On comparing the values of performance indicator for various issues from the reservoir (as per the priority order) from tables 6.3 to 6.7, it is understood that the value of performance indicator for drinking water supply ranges from 0.89 in 3-period (one month) reserve to 0.97 in 15-period (five month) reserve. There is no variation in performance of primary requirement due to change in live storage capacity (varied empty storage requirement) as seen from the tables 6.3 to 6.7. The value of performance indicator for tank supply varies very meagerly from 0.84 to 0.82. The deficiency for tank demand is about 18%, which can be managed with the contribution from the tank catchment area. About 48% of the water requirement for the old command area cannot be fulfilled after satisfying the first three priorities, namely the drinking water demand, tank demand and groundnut demand. . This deficiency is due to the simultaneous water requirement for second and third priorities. The value of performance indicator for old command area ranges from 0.56 to 0.48. The requirement of irrigation water for the groundnut, which is cultivated during mid December month (after the rainfall season), is fulfilled for about 70% of its requirement. The farmers make use of the available ground water for the remaining 30% of their requirement for groundnut. The performance indicator for groundnut (irrigated dry crop) is varying from 0.74 to 0.69.

It can be seen from the table 6.8 that the variation of performance indicator for the cases of with and without new demand does not show significant difference. Hence, the diversion of water for new demand will not affect the overall performance of system. Further, it can be seen from table 6.8 that the reserving water for 15 periods provides reliable supply for the first priority.

Table 6.8 Comparison of performance indicators values for various supplies with or without release to new demand

Reserve period	Drinking water supply		Release to Tank		Release to Groundnut		Release to Old command area	
	Without New demand	With New Demand	Without New demand	With New Demand	Without New demand	With New Demand	Without New demand	With New Demand
3	0.89	0.89	0.84	0.84	0.75	0.74	0.58	0.56
6	0.93	0.92	0.84	0.84	0.75	0.73	0.57	0.54
9	0.95	0.95	0.84	0.84	0.75	0.73	0.56	0.54
12	0.97	0.97	0.83	0.83	0.74	0.71	0.55	0.49
15	0.97	0.97	0.82	0.82	0.73	0.71	0.55	0.53

Table 6.9 Comparison of overall average performance indicators values for various supplies with or without release to new demand

Sl. NO.	Reserve period	Overall average Performance indicator value for all demands	
		With new demand	Without new demand
1.	12	0.77	0.75
2.	15	0.77	0.76

6.7 CONCLUSION

The performance indicator value of the I priority (drinking water supply) in 12 periods reserve is more than that of the 15 periods reserve with the proposed diversion quantity of flow during October and November as 15 million m^3 (new demand). But in the 15 period reserve, the I priority is fulfilled for 97% with 20 million m^3 diversion (new demand) during October and November. Also it is possible to store 15 periods water requirement as a reserve stock in the reservoir for future needs. Moreover from the table 6.9, the overall average performance indicator value (considering all the demands viz., drinking demand, tank demand, groundnut demand and old command demand) for 15 period reserve is marginally higher than 12 period reserve. The performance indicator value for various demands in the case of 15 period-reserve of water is fairly better than that of other cases. Hence the water required for satisfying the primary demand for 15 periods (five months), can be retained in the reservoir as reserve stock even with 20% empty storage capacity in the reservoir (live storage capacity of the reservoir is at 80% of the actual live storage capacity). Moreover 20 million m^3/period of water available during October and November can be drawn from the reservoir for some other useful purpose. The operating policy ensures a firm water release for the supply to the primary demand even in the periods having less live storage in the reservoir. During the monsoon season large quantity of water is wasted as spill. This simulation model modifies the existing operation policy by reserving required quantity of water to satisfy the primary demand, adopting hedging for other demands, which ensures a steady and reliable supply of water.