

## Sustainable Irrigation Allocation Model for Dry and Wet Periods using Reservoir Storage and Inflow

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**Abstract.** The dry period agriculture is inevitable both for the farmers for their earning, and for the soil for its fertility by crop-rotation. In tropical countries like INDIA, dry period agriculture becomes difficult because of less (or) no rain fall. Hence a simple water balancing model for irrigation scheduling, using the measure “Volumetric Reliability” is prepared in this paper, with the storage and inflow of a reservoir both for the dry and wet periods. The case-study is done for a reservoir in INDIA with thirty one years of hydrological data (from 1982 to 2012). The objective of this paper is to prepare a simple water balance model taking 10 days periods of demand and supply for ID crop (Irrigated Dry crop, ground nut) with usage of volumetric reliability concept for the periods of deficiency and adoption of less water requirement crops to reduce the water-stress during critical periods of crop growth, and finally arrive at a feasible allocation schedule for the success of agriculture and the yield throughout the year both for wet and dry crops with the available storage on the start of irrigation for a particular year. The reservoir is divided for storages such as full, deficient and critical storages. The starting storage for the dry period from January is used after adequate allocation for wet crops, the quantity for riparian rights and for drinking water, for the sustainability. By the water-balancing, the time-series for thirty one years, it is found that for twenty two years the demand for the ID crops is satisfied with the storage in the reservoir, and in the remaining years of deficient inflows, for three years (1986, 1996, 2004) the demand is managed by using the safe reliability factor for demand which can nullify the deficit in demand for the whole supply period. But it is genuine to assure that the reduction in the amount of water for each 10 days periods should not exceed the survival limit of the crop. Necessary soil-moisture must be ensured in the crop in its root zone. A safe volumetric reliability factor of 0.75 is taken in this attempt to extend the success of dry period agriculture. The soil moisture balance in the clayey loam soil due to continuous irrigation can manage the deficiency, so that the soil-water does not go below the wilting point but must be checked with the soil-moisture sensors. The methods to reduce the evaporation from the soil, such as usage of drip irrigation and the mulching, which can reduce the crop water requirements in comparison with the conventional irrigation which is being followed at present in the spot of the case-study is suggested. In addition to these methods less water requirement crops like flowers, vegetables having less crop-period and provision of windbreak to reduce evapo-transpiration rates and other efficient methods of water management can make success of dry period agriculture even in the years critical storage level in the reservoir. The rainfall is not taken in this model which if in a year with ample quantity can be used for pre-sowing and for managing the water-stress. Augmentation of water with ground water, percolation tank can boost the level of success of agriculture. As the irrigation water allocation for the whole year, particularly for the ID crops is



prepared for the full, deficient and critical storages, this paper can help to achieve sustainable growth of crops throughout the year.

**Keywords:** ID crops, Volumetric Reliability and Sustainability.

## 1. Introduction

In the present scenario of decrease in rainfall, untimely rainfall, decrease in river flow and increasing population in tropical countries like India where efficient conveyance and application methods in irrigation systems are seldom available, careful planning during allocation of water for irrigation is inevitable, to cater the water needs of the crops not only in the wet periods, but to save the crops from the deficiency of water during dry periods with the available water. Hence an irrigation allocation model for a multipurpose reservoir specifically for the irrigated-dry crops, (id crops) which also includes allocation for wet crops, drinking-water requirement, and quantity as per the riparian rights, is prepared in this paper. Volumetric reliability which is defined as the total volume of water supplied divided by the total demand during a specified period of time is the often used performance measure in rain water tank analysis. In deciding the optimal tank capacity, for the rain water tank system considered on a lot of single dwelling, 5kl tank is found to be adequate for a volumetric reliability of 0.8 than 10KL tank, however when replacing with the vegetables and grasses for garden with some water efficient species 3KL tank would fulfill the requirement according to C.H. Wang and J.M. Black more. The water consumption is optimized so as to get feasible size of water tank in the cost point of view also [1]. This performance measure of volumetric reliability is used in this paper to prepare irrigation water schedule for two things 1. To manage the water stress by reducing the volumetric reliability factor which is taken within safe limit from 1 to 0.75 by which the crop can manage the water stress during the deficient inflow along with the available soil-moisture balance and 2. In addition to usage of volumetric reliability, replacement of water efficient species of grasses, vegetables and flowers instead of the regular dry period crop (ground nut) with efficient conveyance and irrigation methods like drip-irrigation is suggested as id crops which require more water during dry periods. The prime thought in this paper, is that when sufficient storage for the wet crops, water-supply etc, is reserved in a reservoir, a better water allocation schedule for the id crops is inevitable, genuinely for the deficient and critical storages, and can be used for sustainable irrigation during the whole year in a command area. By the success of ID crops the net benefit from agriculture can be ensured. The constraints are maximum, deficient, and critical reservoir storages which depend on the inflow into the reservoir. The optimal operation of multi purpose reservoir for irrigation planning using surface and ground water is discussed by Nikam N.G et.al [2]. The critical water level for a soil below which the crops will be stressed is important. The reduced yield of crop is related to its growth stage and to the amount and duration that the soil water content is below this optimum value. Solutions to complex decision making problems are currently available for a variety of irrigation situation an integrated model is developed and is made of two modules one for intra seasonal allocation using lp and two for seasonal allocation to derive steady state reservoir operating policy as per Martin M. Fogel et al. [3]. A short review of the mathematical models used in reservoir management and operation to present conclusions reached by previous state of art reviews, and to provide two ideas for closing the gap between theory and practice according to Slobodan P. Simonovic [4]. Water supply yield analysis techniques are developed to adequacy of wma water supply system to meet the escalating future demands for water. Historic yield values for the joint system yield model exceed 700mgd, indicating that the current water supply system is quite reliable according to James A. Smith [5]. When design is applied in direct consultation with water users the system makes local water distribution more transparent and effective overall reliability = (actual volume delivered / planned volume) x actual supply duration / target supply duration according to Islander Abdulla et.al [6]. Reliability provides the inducement for farmers to invest in higher productivity to benefit individuals and society mapping of reliability and productivity through remote sensing is attempted sustainably, according to Chris Perry [7]. The investigation strategies to alleviate the effects of drought on the probability and sustainability of irrigated agriculture this include conjunctive use of surface and

ground water resources the simulation model consists of agronomic component and simulators for the system according to Gerritschoups et al [8]. According to S. Vedula, D. NageshKumar, the. Optimal seasonal multi crop irrigation water allocation and optimal stochastic intra seasonal in irrigation scheduling are carried out using two stage decomposition based on a stochastic dynamic programming method [9]. A optimal stochastic multi crop seasonal and intra seasonal irrigation control model is prepared by Judith A Sunantara et al [10]. The loss due to conveyance and the loss from soil surface can be reduced by adopting drip irrigation along with mulching. This will reduce the crop water requirement according to Battikhi and Hill [11]. Generally as the dry period agriculture is important for farmers for their earning, crop-rotation and food production which will generally have set-backs due to less availability of water and other reasons an attempt is made in this paper to analyze the possibility of success for dry crop by water scheduling using the operator “volumetric reliability”.

### *1.1 The need for water scheduling*

Irrigation is the predominant sector where water requirement quantity is more than 85% in low and middle income group countries, where agriculture is the major economic sector (World Bank 1992). But the irrigated agriculture faces water stress due to shortages in demand. The demands of irrigation water have dependability on decisions for a particular period taken by the farmers which in turn depends on the type of crop and its period of growth. The water requirement decisions is generally based on 1. long term crops 2. Short-term crops. The food crops and the long term crops are generally given priority during the decisions for water allocations from a Reservoir. Hence, the crops sown during dry period, which is important for crop rotation and earning for farmers during dry season, is given secondary importance. Due to the fact that food crops like paddy, wheat are developed during wet season they have more chances of getting adequate water supply from a reservoir as well as from rainfall. But the farmers will be finding much difficult to do dry period agriculture because of the less amount of water available after allocation to wet crop irrigation and other components of demands for a multi-purpose reservoir. Also due to the stochastic nature of the inflow into the reservoir and rainfall in the agricultural field, there will be inadequate water for dry crop irrigation and sometimes it'll be severe to the extent that no agriculture can be carried using reservoir supply during dry period by the farmers. An attempt is made in this paper to manage the water stress during dry period using the reliability criteria, usage of less water requirement crops during the dry period to make the agriculture success to the possible extent. The standard water balancing equation and the simulation is used for the water allocation model in this paper. The Sathanur reservoir built in the year 1960, constructed across Poniyar river in India is taken as the case study. The hydrological and hydraulic data with the history of the reservoir and all other details are collected for 31 years (1982—2012). This is a multi-purpose reservoir, which is satisfying the irrigation needs of the south Arcot district, in addition to the needs of drinking water supply for Tiruvannamalai city, hydro electricity power generation etc., This dam is mainly constructed to supply irrigation water during the dry season from December to April of every year in which there will be less rainfall and for the successful agriculture of Irrigated-Dry crops (ID crops). But due to the stochastic nature of the inflow which is the predominant factor for the ID-crop irrigation water, it is found that reliable water supply cannot be assured if the inflow in to the reservoir is very less (or) less than its demand. In this paper water balancing model is prepared for the irrigation water of ID crops, for managing the water-stress during periods of less inflow using the standard water balancing and the use of operator Reliability to the extent possible, during dry inflow periods. Out of 31 years, eight years were found to be deficient in satisfying the demand, but by using the operators 3 years out of 8 years, the deficiency is managed.

### *1.2 Study area details*

The area of case study is the Sathanur reservoir constructed during 1958, near Tiruvannamalai Town, North Arcot District, Tamilnadu, India. It is located across the river Ponnaiar. Its Catchment area is 10835 km<sup>2</sup>. The length of the Masonry Dam is 418 m and the length of the earth Dam is 362 m. The height of Masonry Dam is 45 m above foundations. The Capacity of Reservoir is 229 million m<sup>3</sup> and

the live storage capacity is 207 million m<sup>3</sup>. The spillway has 9 Vents of 12.2 m x 6.1 m. The capacity of Saddle Spillway is 2234 m<sup>3</sup>/s. Average inflow (1987-2007): 314.08 million m<sup>3</sup> per year. The length of the river is 7.2 km up to pickup weir. Period of wet season is September to January and the Period of dry season: December – March. Command area under wet period is 3020 hectare and the crop is paddy. The Command area under dry period is 15200 hectares and the ID crop is ground nut. There are two main canals such as LBC (left main canal), RBC (right main canal) supplying water for the crops for both the seasons. The salient features of dam (i) Capacity of the reservoir – 340 million cu.m (ii) No. of fillings – 20 out of 55 years (iii) Annual Storage – 6796 million cu.m (iv) Water spread area – 126.66 ha (v) Catchments area – 87.023 sq.m (vi) Area submerged – 102.935 ha (vii) Total dependable yield available at site – 10.26 million cu.m (viii) New command area – 740.57 ha (ix) Old command area – 109.67 ha (x) Number of spillway – 2 nos. The irrigated area after the constructions of the dam has been increased, additional area of irrigation was achieved in addition to the demands for the riparian rights.

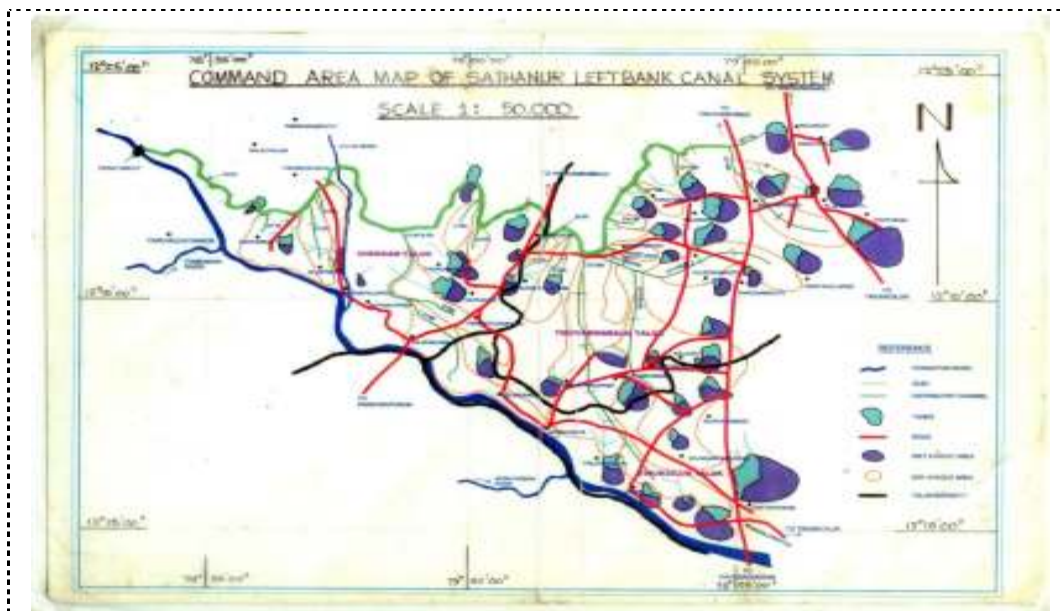


**Figure 1.** Command area map of the Sathanur Reservoir

The scope of this paper is to arrive at an appropriate allocation decision model for dry crops by evaluating the reliability of water allocation model with the starting storage, inflow into the reservoir which is the predominant factors as sufficient, moderately deficient, and highly deficient supplies, by simulating the starting storage and the inflow on January 1 of the respective year until a positive allocation model is arrived by the usage of operator, “volumetric Reliability”, change of crop having less water requirement, and using efficient irrigation methods.,

**Table 1.** Details of reservoir levels for 55 years.

| S. No. | Year |   |      | Maximum Water Level in ft | Capacity in Mcft | Reservoir Filled | Reservoir Not Filled |
|--------|------|---|------|---------------------------|------------------|------------------|----------------------|
| 1      | 1958 | - | 1959 | 102.80                    | 5112             | Filled           | -                    |
| 2      | 1959 | - | 1960 | 103.30                    | 5188             | Filled           | -                    |
| 3      | 1960 | - | 1961 | 102.10                    | 5040             | Filled           | -                    |
| 4      | 1961 | - | 1962 | 74.40                     | 1947             | -                | Not filled           |
| 5      | 1962 | - | 1963 | 90.25                     | 4739             | -                | Not filled           |
| 6      | 1963 | - | 1964 | 100.20                    | 4732             | -                | Not filled           |
| 7      | 1964 | - | 1965 | 109.30                    | 6178             | -                | Not filled           |
| 8      | 1965 | - | 1966 | 90.65                     | 3502             | -                | Not filled           |
| 9      | 1966 | - | 1967 | 117.95                    | 7859             | -                | Not filled           |
| 10     | 1967 | - | 1968 | 119.00                    | 8083             | Filled           | -                    |
| 11     | 1968 | - | 1969 | 118.55                    | 7987             | -                | Not filled           |
| 12     | 1969 | - | 1970 | 118.95                    | 8072             | -                | Not filled           |
| 13     | 1970 | - | 1971 | 118.35                    | 7944             | -                | Not filled           |
| 14     | 1971 | - | 1972 | 118.90                    | 8062             | -                | Not filled           |
| 15     | 1972 | - | 1973 | 122.50                    | 8736             | Filled           | -                    |
| 16     | 1973 | - | 1974 | 117.35                    | 7733             | -                | Not filled           |
| 17     | 1974 | - | 1975 | 117.00                    | 7659             | -                | Not filled           |
| 18     | 1975 | - | 1976 | 118.40                    | 7955             | -                | Not filled           |
| 19     | 1976 | - | 1977 | 78.85                     | 2308             | -                | Not filled           |
| 20     | 1977 | - | 1978 | 119.00                    | 8083             | Filled           | -                    |
| 21     | 1978 | - | 1979 | 119.00                    | 8083             | Filled           | -                    |
| 22     | 1979 | - | 1980 | 119.00                    | 8083             | Filled           | -                    |
| 23     | 1980 | - | 1981 | 79.65                     | 2378             | -                | Not filled           |
| 24     | 1981 | - | 1982 | 119.00                    | 8083             | Filled           | -                    |
| 25     | 1982 | - | 1983 | 73.75                     | 1903             | -                | Not filled           |
| 26     | 1983 | - | 1984 | 94.20                     | 3933             | -                | Not filled           |
| 27     | 1984 | - | 1985 | 95.05                     | 4040             | -                | Not filled           |
| 28     | 1985 | - | 1986 | 87.40                     | 2178             | -                | Not filled           |
| 29     | 1986 | - | 1987 | 118.10                    | 7119             | -                | Not filled           |
| 30     | 1987 | - | 1988 | 101.80                    | 4026             | -                | Not filled           |
| 31     | 1988 | - | 1989 | 114.95                    | 6431             | -                | Not filled           |
| 32     | 1989 | - | 1990 | 83.25                     | 1788             | -                | Not filled           |
| 33     | 1990 | - | 1991 | 68.90                     | 794              | -                | Not filled           |
| 34     | 1991 | - | 1992 | 119.00                    | 7321             | Filled           | -                    |
| 35     | 1992 | - | 1993 | 119.00                    | 7321             | Filled           | -                    |
| 36     | 1993 | - | 1994 | 119.00                    | 7321             | Filled           | -                    |
| 37     | 1994 | - | 1995 | 115.20                    | 6484             | -                | Not filled           |
| 38     | 1995 | - | 1996 | 108.10                    | 4725             | -                | Not filled           |
| 39     | 1996 | - | 1997 | 119.00                    | 7321             | Filled           | -                    |
| 40     | 1997 | - | 1998 | 119.00                    | 7321             | Filled           | -                    |
| 41     | 1998 | - | 1999 | 119.00                    | 7321             | Filled           | -                    |
| 42     | 1999 | - | 2000 | 118.50                    | 7209             | -                | Not filled           |

|    |      |   |      |        |      |        |            |
|----|------|---|------|--------|------|--------|------------|
| 43 | 2000 | - | 2001 | 117.30 | 6942 | -      | Not filled |
| 44 | 2001 | - | 2002 | 117.10 | 6897 | -      | Not filled |
| 45 | 2002 | - | 2003 | 78.75  | 1415 | -      | Not filled |
| 46 | 2003 | - | 2004 | 91.70  | 2648 | -      | Not filled |
| 47 | 2004 | - | 2005 | 119.00 | 7321 | Filled | -          |
| 48 | 2005 | - | 2006 | 119.00 | 7321 | Filled | -          |
| 49 | 2006 | - | 2007 | 97.20  | 3358 | -      | Not filled |
| 50 | 2007 | - | 2008 | 115.45 | 6538 | -      | Not filled |
| 51 | 2008 | - | 2009 | 119.00 | 7321 | Filled | -          |
| 52 | 2009 | - | 2010 | 107.10 | 4901 | -      | Not filled |
| 53 | 2010 | - | 2011 | 119.00 | 7321 | Filled | -          |
| 54 | 2011 | - | 2012 | 119.00 | 7321 | Filled | -          |
| 55 | 2012 | - | 2013 | 89.00  | 2342 | -      | Not filled |

## 2. Objective

By adopting a safe volumetric reliability factor for the irrigation water supplied to the crop, during deficit inflow, the success of dry crop and the benefit can also achieved. The objective function is written as

1. Maximize Z1 = Maximize Reliability of irrigation = R (t)

2. Maximize Z2 = Maximize benefit B (t) / yield (t).

R<sub>v</sub>= volumetric reliability is the measure used. = Volume of supply / Volume of Demand for 10 day periods. By increasing the reliability the level of success of agriculture as well as benefit can be achieved.

The standard water balancing equation and consecutive simulation is done for each 10 day periods. Water balancing equation used is,

$$S_t + I_t - L_t - D_t = S_{t+1}, \quad (1)$$

Where, t=1, 2, 3... n periods of crop each of 10 days period. And

S<sub>t</sub> =Storage in the reservoir, at the start of irrigation in Mm3, I<sub>t</sub> =Inflow during t (10days), D<sub>t</sub> = Irrigation requirement during t, (0.75 times the inflow is only taken as I to account for the losses.) S<sub>t+1</sub>= Storage at the start of t+1 period.  
Where

$$R_v = \frac{\sum_{k=1}^n s}{\sum_{k=1}^n D} \quad (2)$$

0.75 ≤ R<sub>v</sub> ≤ 1 for 9 periods from k=1 to n

Where R<sub>v</sub> is the volumetric reliability.

By increasing the R<sub>v</sub>, the yield can be increased (or) maximized upto when R<sub>v</sub> =1

Where,  $\sum_{k=1}^n s$  = total supply during a period (10 days) for the dry crop

$\sum_{k=1}^n D$  = total demand during a period (10 days) for the dry crop  
 $Y$  = Yield from the agriculture

The value of  $R=1$  for full and medium storage. The value of  $R_v$  is reduced from 1 to 0.75 for deficient and severe storages. The reliability of irrigation is assessed every year by simulating the time series of storage, inflow and demand using the water balance equation as in methodology.

### 3. Methodology

The reservoir is divided in to three zones like safe storage (207 to 100 M m<sup>3</sup>), deficient storage (100 to 50 M m<sup>3</sup>) and critical storage (below 50 M m<sup>3</sup>). From the year 1982 to 2012, with the time series, the inflow, the irrigation requirement is simulated using The Standard Water Balancing Equation. For the years of deficient storage the Volumetric Reliability factor of 0.75 is used to come over the water stress and for the success of the dry crop. The flowchart for the run of the model with suggestions for the critical periods is also given below.



**Figure 2.** Zones of Reservoir Storage

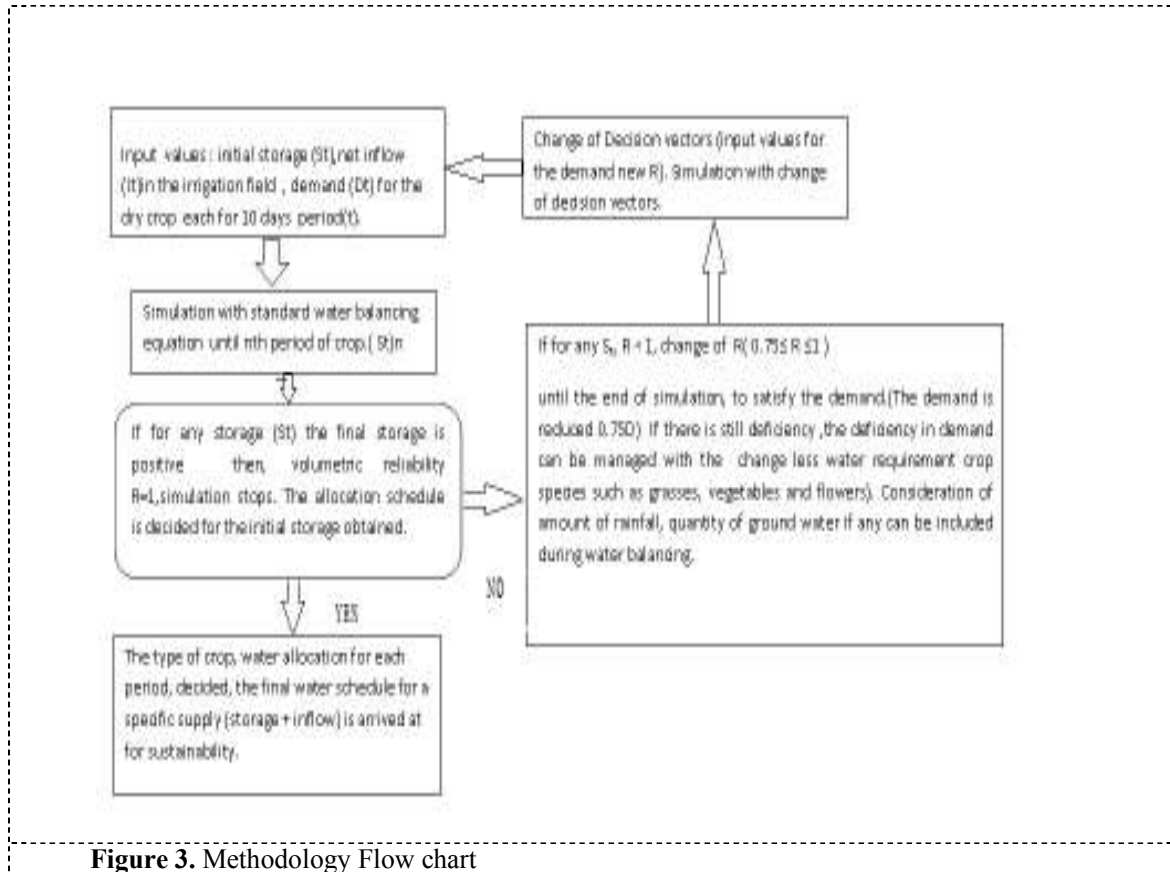


**Figure 3.** Methodology Flow chart

### 3.1 Steps of Calculations of demand and supply for water balancing

- i. The demand and supply calculations are made for 10 days periods and simulated starting from the storage on January 1 for 9 periods for the ID crop for all the 31 years (1982-2012) the demand for all 36 periods of the year is calculated taking the priorities for the riparian rights, drinking water requirement and wet crops.
- ii. The demand is calculated by using Blaney-criddle method using the details of data obtained from the standard hydrological data for the area.
- iii. The consumptive use for 10 days period for ground nut is calculated by
- iv.  $C_u = k_p / 40 (1.8t + 32)$ , where,  $C_u$  = monthly consumptive use in 'mm'. The values for the  $k_p$ ,  $t$  is obtained for the periods using standard reference book for the command area, prepared by the government. The total command area is 15,045 hectares for two canals namely left bank canal and right bank canal.
- v. The supply (initial storage + inflow) on January 1 for each 31 years with inflows, is water balanced with the demand for all 9 periods for ID crops using standard water balancing and for deficient and critical periods the deficiency of water is checked with the volumetric reliability factor of 0.75 to manage the water stress, and suggestive methods are given to relieve from water-stress to the extent possible.

**Table 2.** Demand for dry crop (ID) Ground nut and others

| Crop water requirement in mm (10days) | Area in hectares | Depth in m | Volume in cu.m | Volume in cu.m | Other allocations (dr.wtr+rap.ri) Million cum | Total req. for ID crop period M cum |
|---------------------------------------|------------------|------------|----------------|----------------|-----------------------------------------------|-------------------------------------|
| 12.87                                 | 15045            | 0.013      | 1955854        | 1.96           | 1                                             | 2.96                                |
| 18                                    | 15045            | 0.018      | 2735460        | 2.74           | 5.28                                          | 8.02                                |
| 22.84                                 | 15045            | 0.023      | 3470995        | 3.47           | 3.57                                          | 7.04                                |
| 28.6                                  | 15045            | 0.029      | 4346342        | 4.35           | 1                                             | 5.35                                |
| 38.84                                 | 15045            | 0.039      | 5902515        | 5.9            | 1                                             | 6.9                                 |
| 41.4                                  | 15045            | 0.041      | 6291558        | 6.29           | 4.4                                           | 10.69                               |
| 35.45                                 | 15045            | 0.035      | 5387337        | 5.39           | 4.43                                          | 9.82                                |
| 37                                    | 15045            | 0.037      | 5622890        | 5.62           | 3.83                                          | 9.45                                |
| 33                                    | 15045            | 0.033      | 5015010        | 5.02           | 3.83                                          | 8.85                                |
| 268                                   |                  |            |                | 40.73          | 28.34                                         | 69.07                               |

**Table 3.** Demand Calculations(CWR) for ID crop including priorities for other requirements

| S. No. | AREA (in Hec) | Depth (in m) | Vol. (in m3) | Other allocations (Million cu.m) | ID crop (Million cu.m) | Total (Million cu.m) | Field requirement considering losses 25% (M cu.m) |
|--------|---------------|--------------|--------------|----------------------------------|------------------------|----------------------|---------------------------------------------------|
| 1.     | 15197         | 0.013        | 1955854      | 1                                | 1.96                   | 2.96                 | 3.94                                              |
| 2      | 15197         | 0.018        | 2735460      | 5.28                             | 2.74                   | 8.02                 | 10.68                                             |
| 3      | 15197         | 0.023        | 3470995      | 3.57                             | 3.47                   | 7.04                 | 9.38                                              |
| 4      | 15197         | 0.029        | 4346342      | 1                                | 4.35                   | 5.35                 | 7.12                                              |
| 5      | 15197         | 0.039        | 5902515      | 1                                | 5.90                   | 6.90                 | 9.20                                              |
| 6      | 15197         | 0.041        | 6291558      | 4.4                              | 6.29                   | 10.69                | 14.25                                             |
| 7      | 15197         | 0.035        | 5387337      | 4.43                             | 5.39                   | 9.82                 | 13.08                                             |
| 8      | 15197         | 0.037        | 5622890      | 3.83                             | 5.62                   | 9.45                 | 12.60                                             |
| 9      | 15197         | 0.033        | 5015010      | 3.83                             | 5.02                   | 8.85                 | 11.79                                             |
| Total  |               |              |              |                                  | 40.73                  | 69.07                | 92.09                                             |

**Table 4.** Table showing the actual demand in the field including losses

| Total CWR in the head of canal (M cu.m) | Total CWR in the field including losses taken as 25% (M cu.m) |
|-----------------------------------------|---------------------------------------------------------------|
| 2.96                                    | 3.94                                                          |
| 8.02                                    | 10.69                                                         |
| 7.04                                    | 9.39                                                          |
| 5.35                                    | 7.13                                                          |
| 6.90                                    | 9.20                                                          |
| 10.69                                   | 14.26                                                         |
| 9.82                                    | 13.09                                                         |
| 9.45                                    | 12.60                                                         |
| 8.85                                    | 11.79                                                         |
| 69.07                                   | 92.09                                                         |

**Table 5.** Allocations for wet crop and riparian rights etc., for 36 periods of the year

| Month | Priorities With<br>Periods(10<br>Days ) | Drink.Wat<br>1 | Tank Dem<br>2 | ID (Gr.Nut)<br>3 | Down Stream<br>Command<br>Demand(Thirukoil) 4 |
|-------|-----------------------------------------|----------------|---------------|------------------|-----------------------------------------------|
| Jan   | 1                                       | 1              | 0             | 2.96             | 0                                             |
|       | 2                                       | 1              | 4.28          | 8.02             | 0                                             |
|       | 3                                       | 1              | 2.57          | 7.04             | 0                                             |
| Feb   | 1                                       | 1              | 0             | 5.35             | 0                                             |
|       | 2                                       | 1              | 0             | 6.90             | 0                                             |
|       | 3                                       | 1              | 3.4           | 10.69            | 0                                             |
| Mar   | 1                                       | 1              | 3.43          | 9.82             | 0                                             |
|       | 2                                       | 1              | 2.83          | 9.45             | 5.67 During 2, 3 pds of<br>March.             |
|       | 3                                       | 1              | 2.83          | 8.85             |                                               |
| Apr   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| May   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| June  | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| July  | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| Aug   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| Sep   | 1                                       | 1              | 9.5           |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| Oct   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| Nov   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 0             |                  | 0                                             |
| Dec   | 1                                       | 1              | 0             |                  | 0                                             |
|       | 2                                       | 1              | 0             |                  | 0                                             |
|       | 3                                       | 1              | 13.61         |                  | 0                                             |

**Table 6.** Water balancing for deficient storage for the year 2004

| St       | It   | dt    | Total    |
|----------|------|-------|----------|
| 74.98524 | 0    | 3.94  | 71.04411 |
| 71.04411 | 0    | 10.69 | 60.35683 |
| 60.35683 | 0    | 9.39  | 50.96883 |
| 50.96883 | 1.25 | 7.13  | 45.09038 |
| 45.09038 | 0    | 9.20  | 35.88702 |
| 35.88702 | 0    | 14.26 | 21.63161 |
| 21.63161 | 0    | 13.09 | 8.541831 |
| 8.541831 | 0    | 12.60 | -4.06202 |
| -4.06202 | 0    | 11.79 | -15.8554 |
|          |      | 92.09 |          |

**Table 7.** Water balancing for deficient storage for 2004 using volumetric reliability of ( $R_v$ )0.75 in demand

| St       | It   | dt    | Total    |
|----------|------|-------|----------|
| 74.98524 | 0    | 2.96  | 72.02939 |
| 72.02939 | 0    | 8.02  | 64.01393 |
| 64.01393 | 0    | 7.04  | 56.97294 |
| 56.97294 | 1.25 | 5.35  | 52.87659 |
| 52.87659 | 0    | 6.90  | 45.97408 |
| 45.97408 | 0    | 10.69 | 35.28252 |
| 35.28252 | 0    | 9.82  | 25.46518 |
| 25.46518 | 0    | 9.45  | 16.01229 |
| 16.01229 | 0    | 8.85  | 7.167284 |

**Table 8.** Water balancing for storage (st=storage at time): it, dt(inflow, demand during t)-2002

| St       | It       | dt    | St+1     |
|----------|----------|-------|----------|
| 201.9379 | 21.13633 | 3.94  | 219.1331 |
| 219.1331 | 1.763135 | 10.69 | 210.209  |
| 210.209  | 0        | 9.39  | 200.821  |
| 204.6534 | 0        | 7.13  | 197.525  |
| 197.525  | 0        | 9.20  | 188.3216 |
| 188.3216 | 0        | 14.26 | 174.0662 |
| 174.1084 | 0        | 13.09 | 161.0186 |
| 161.0186 | 0        | 12.60 | 148.4148 |
| 148.4148 | 0        | 11.79 | 136.6214 |
|          |          | 92.09 |          |

**Table 9.** Water balancing for critical storage for the year 1986

| St    | It   | dt    | St+1  |
|-------|------|-------|-------|
| 57.96 | 1.11 | 3.94  | 55.12 |
| 55.12 | 7.23 | 10.69 | 53.63 |
| 53.63 | 2.98 | 9.39  | 49.08 |
| 49.08 | 1.30 | 7.13  | 44.52 |
| 44.52 | 0.83 | 9.20  | 30.42 |
| 30.42 | 0.45 | 14.26 | 21.12 |
| 21.12 | 0.69 | 13.09 | 11.39 |
| 11.39 | 0.56 | 12.60 | 1.53  |
| 1.53  | 0.37 | 11.79 | -8.52 |

**Table 10.** Water balancing for critical storage for 1986 using volumetric reliability of 0.75 in demand and water stress is managed with the inflow

| St    | It   | dt       | st+1     |
|-------|------|----------|----------|
| 57.96 | 1.11 | 2.951295 | 56.11072 |
| 56.11 | 7.23 | 8.01546  | 55.33    |
| 55.33 | 2.98 | 7.037955 | 51.26    |
| 51.26 | 1.30 | 5.331145 | 47.23    |
| 47.23 | 0.83 | 14.59719 | 33.47    |
| 33.47 | 0.45 | 10.72156 | 23.20    |
| 23.20 | 0.69 | 5.984616 | 17.90    |
| 17.90 | 0.56 | 6.312871 | 12.15    |
| 12.15 | 0.37 | 6.62289  | 5.90     |
|       |      | 67.57    |          |

*3.2 Design schedule for water allocations:*

Normal season: Storage = 207 M cu.m

**Table 11.** Existing Schedule in operation by the government (Values in Million cu.m)

| Case              | Storage | To colony (ws) | Dead storage | II crop (riparian rights) | Drinking water supply | Total deduction | Wet crop | Dry crop | Remarks                                                                                             |
|-------------------|---------|----------------|--------------|---------------------------|-----------------------|-----------------|----------|----------|-----------------------------------------------------------------------------------------------------|
| Full storage      | 207     | 19             | 9            | 34                        | 8                     | 70              | 23       | 114      | 12 spells with summer irrigation for 15000 hectares, 3164 hec of paddy and 2023 hec of second crop. |
| Deficient storage | 100     | 17             | 9            | -                         | 8                     | 34              | 13       | 53       | 8 spells of two third supply, 10000 hectares of summer irrigation.                                  |
| Scarcity season   | 70      | 13             | 9            | -                         | 8                     | 30              | 13       | 27       | 8 spells of One third supply of 6755 hec of summer irrigation.                                      |

**Table 12.** Hypothetical schedule of allocations

| Case              | Storage | To colony (ws) | Dead storage | II crop (riparian rights) | Drinking water supply | Total deduction | Wet crop | Dry crop | Remarks                                                                                                                                                                                                |
|-------------------|---------|----------------|--------------|---------------------------|-----------------------|-----------------|----------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Full storage      | 207     | 19             | 9            | 34                        | 8                     | 70              | 23       | 114      | 12 spell considering full area both for summer, wet, and II crops.                                                                                                                                     |
| Deficient storage | 100     | 17             | 9            | -                         | 8                     | 34              | 13       | 53       | 8 spells of two third supply considering the full area for summer crop, wet crop, and II crop if there is scope (supply with volumetric reliability of 0.75, and monitoring the minimum soil moisture) |
| Scarcity storage  | 70      | 13             | 9            | -                         | 8                     | 30              | 13       | 27       | 8 spells of One third supply with much reduction in agricultural area.(Supply with volumetric reliability of 0.75 can increase the area of agriculture )                                               |

**Table 13.** Statement showing the average monthly rainfall of sathanur dam Rainfall Station

| Jan    | Feb   | Mar  | Apr    | May   | Jun   | Jul   | Aug    | Sep    | Oct    | Nov    | Dec    | Total   |
|--------|-------|------|--------|-------|-------|-------|--------|--------|--------|--------|--------|---------|
| 11.688 | 9.135 | 13.9 | 18.125 | 86.12 | 51.88 | 72.79 | 109.95 | 162.19 | 193.52 | 166.97 | 82.658 | 978.923 |

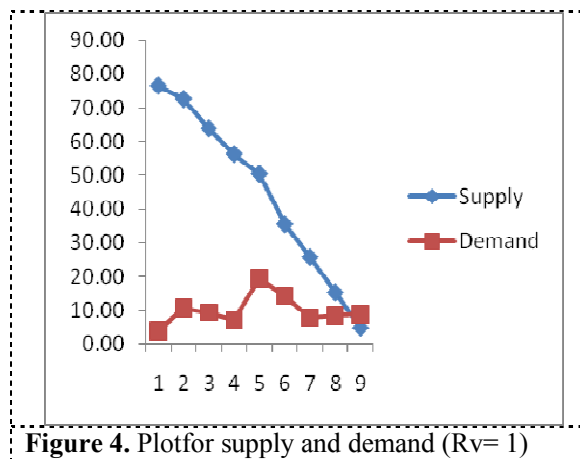
**Table 14.** Command area for Sathanur dam in hectares

| Canals | Dry Crop (Ha) | Wet Crop (Ha) |
|--------|---------------|---------------|
| SLBC   | 8638          | 1130          |
| SRBC   | 6559          | 1890          |
| TOTAL  | 15197         | 3020          |

SLBC –sathanur left bank canal: SRBC sathanur right bank canal

**Table 15.** Water balancing with normal values for the year1996

| St    | it   | dt    | st+1  |
|-------|------|-------|-------|
| 76.46 | 0.14 | 3.94  | 72.67 |
| 72.67 | 0.00 | 10.69 | 63.94 |
| 63.94 | 0.00 | 9.38  | 56.42 |
| 56.42 | 0.00 | 7.11  | 50.55 |
| 50.55 | 0.00 | 19.46 | 35.62 |
| 35.62 | 0.00 | 14.30 | 25.87 |
| 25.87 | 0.00 | 7.98  | 15.45 |
| 15.45 | 0.00 | 8.42  | 5.03  |
| 5.03  | 0.00 | 8.83  | -5.39 |

**Figure 4.** Plot for supply and demand ( $R_v = 1$ )**Table 16.** Water balancing with normal values for the year1996 using ( $R_v$ ) =0.75

| St    | it   | dt    | st+1  |
|-------|------|-------|-------|
| 76.46 | 0.14 | 2.95  | 73.65 |
| 73.65 | 0.00 | 8.02  | 65.63 |
| 65.63 | 0.00 | 7.04  | 58.60 |
| 58.60 | 0.00 | 5.33  | 53.27 |
| 53.27 | 0.00 | 14.60 | 38.67 |
| 38.67 | 0.00 | 10.72 | 27.95 |
| 27.95 | 0.00 | 5.98  | 21.96 |
| 21.96 | 0.00 | 6.31  | 15.65 |
| 15.65 | 0.00 | 6.62  | 9.03  |

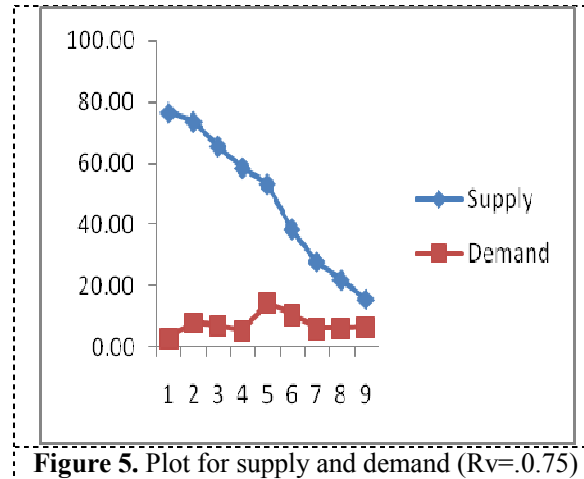


**Figure 5.** Plot for supply and demand ( $R_v=0.75$ )

**Table 17.** Water balancing with normal values for the year 1986

| St    | it   | dt    | st+1  |
|-------|------|-------|-------|
| 57.96 | 1.11 | 3.94  | 55.13 |
| 55.13 | 7.23 | 10.69 | 53.63 |
| 53.63 | 2.98 | 9.38  | 49.08 |
| 49.08 | 1.30 | 7.11  | 44.52 |
| 44.52 | 0.83 | 19.46 | 30.42 |
| 30.42 | 0.45 | 14.30 | 21.12 |
| 21.12 | 0.69 | 7.98  | 11.39 |
| 11.39 | 0.56 | 8.42  | 1.53  |
| 1.53  | 0.37 | 8.83  | -8.52 |

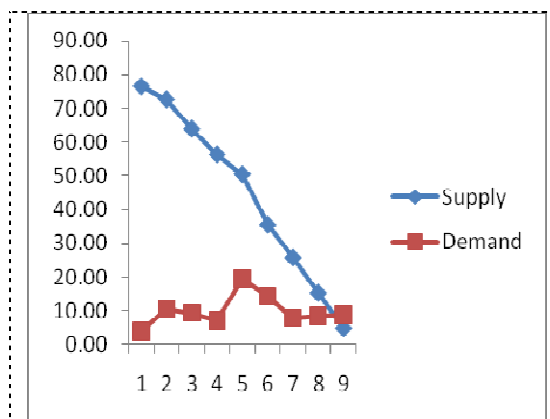


**Figure 6.** Plot for supply and demand ( $R_v=1$ )

#### 4. Results and Discussion

The annual inflow in to the reservoir in the ascending order of lowest, middle and highest in quantity among each consecutive 5 years is taken and simulated using standard water balance equation for the set of data from 1982 to 2012 (31 years). Out of 31 years 8 years the demand was not satisfied or deficient and by using the volumetric reliability it was found that for 3 years the water deficiency can be managed. For the remaining years of irrigation water deficiency the very less water requirement crop than groundnut with efficient methods of irrigation such as drip and sprinkler irrigation, with augmentation of groundwater can save the ID crops making sustainable irrigation through the year.

The rain fall is scarce and if there is rainfall in a year it can augment the irrigation requirement along with groundwater and saving in percolation ponds during excess year. In the allocation schedule prepared by the government, the area of irrigation for dry period is reduced according to the storage. But the total area of 15,045 hectares is taken for ID crops in this model for all the 31 years.

**Table 18.** Water balancing with normal values for the year 1986 using ( $R_v$ )=0.75

| St    | it   | dt    | st+1  |
|-------|------|-------|-------|
| 57.96 | 1.11 | 2.95  | 55.92 |
| 55.92 | 7.23 | 8.02  | 55.13 |
| 55.13 | 2.98 | 7.04  | 51.07 |
| 51.07 | 1.30 | 5.33  | 47.04 |
| 47.04 | 0.83 | 14.60 | 33.27 |
| 33.27 | 0.45 | 10.72 | 23.00 |
| 23.00 | 0.69 | 5.98  | 17.71 |
| 17.71 | 0.56 | 6.31  | 11.96 |
| 11.96 | 0.37 | 6.62  | 5.70  |

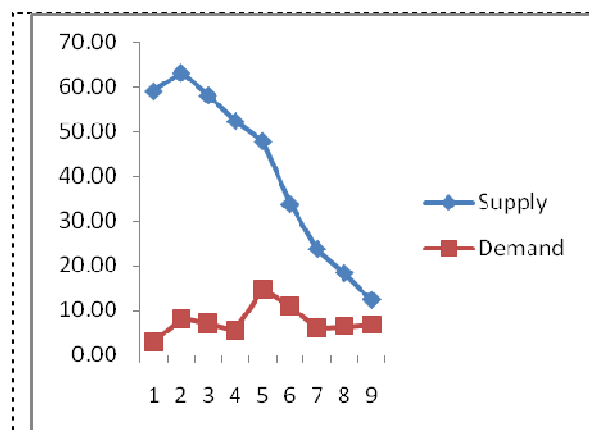


**Figure 7.** Plot for supply and demand ( $R_v$ =0.75)

Out of 55 years (from 1957 -2012) the dam got filled for 20 years and with in the remaining years 13 years the storage was critical making water stress for ID crops. The water balancing and usage of volumetric reliability is done for 31 years(1982-2012). ( The table numbers 16,18 and the figures 4,5,6 and 7 shows how the reduced demand is satisfied using  $R_v$ ) The model gives the water scheduling for three deficient years to make it success out of 8 years. For the remaining years of deficient and critical flows suggestions are given to over come the water-stress. Out of the hydrological parameters such as the reservoir inflow, rainfall and storage at the start of irrigation for the ID crops, the storage at the start is the only known parameter to decide the pattern of ID crops. As the period of ID crops starts from January coincides with opening of water for irrigation from reservoir storages up to December every year the ID crops can have probability of the propotionly ample amount of water for its allocation, with its storage. This model requires the prediction of inflow in to the reservoir which can be assessed by the rainfall in the catchment area. The rainfall which is not the reliable parameter during dry period is not taken in this model, if any can help for requirements during pre-sowing, mid or end periods of crop growth if in a particular year. Even though this work is hypothetical, it can be made practically possible by checking the soil moisture balance during each day of the crop period to ensure the minimum available moisture in the root zone of the crop, using soil

moisture meters and sophisticated instruments which is a must for the adoption of this model in the field and finally the survival and success of ID crops can be achieved.

**Table 19.** Results and Discussions

| Year                                                                                                                                                                                                                     | Storage<br>(in Mm <sup>3</sup> ) | Inflow(in<br>Mm <sup>3</sup> ) | Usage of volumetric Reliability criteria ,rainfall for<br>managing the water stress |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------|-------------------------------------------------------------------------------------|
| Deficiency in Demand, over coming using (R <sub>v</sub> )                                                                                                                                                                |                                  |                                |                                                                                     |
| 1996                                                                                                                                                                                                                     | 76.46                            | 0.14                           | -5.39                                                                               |
| Using R=0.75,the deficiency is reduced from - 5.39 to +9.02 , no rainfall, usage of limited ground water along efficient methods can increase the volumetric reliability from 0.75 to 1                                  |                                  |                                |                                                                                     |
| 1986                                                                                                                                                                                                                     | 57.95                            | 15.52                          | -8.52                                                                               |
| Using R=0.75, the deficiency is reduced from - 8.52 to + 5.7, rainfall of 13.3 can augment. usage of limited ground water along efficient methods can increase the volumetric reliability from 0.75 to 1                 |                                  |                                |                                                                                     |
| 2004                                                                                                                                                                                                                     | 74.98                            | 1.25                           | -15.85                                                                              |
| Using R=0.75,the deficiency is reduced from - 15.85 to +7.16 , rainfall of 4.20 cm can augment usage of limited ground water along efficient methods can increase the volumetric reliability from 0.75 to 1              |                                  |                                |                                                                                     |
| 1989                                                                                                                                                                                                                     | 56.87                            | 2.05                           | -23.07                                                                              |
| Using R=0.75, the deficiency is reduced -23.07 to -8.64 , rainfall of 6.00 can augment, the deficiency and the reliability can be increased by other measures as given above.                                            |                                  |                                |                                                                                     |
| 1983                                                                                                                                                                                                                     | 53.18                            | 1.41                           | -27.39                                                                              |
| No rainfall but suggestive methods of crops with less CWR and efficient methods of irrigation can be adopted. (Drip, sprinkler methods, mulching etc), with reduction in area for ID crops to meet out the water stress. |                                  |                                |                                                                                     |
| 1990                                                                                                                                                                                                                     | 31.47                            | 3.55                           | -46.96                                                                              |
| Even though a rainfall of 18 M m <sup>3</sup> can manage the water stress to some extent other measures can be carried out.                                                                                              |                                  |                                |                                                                                     |
| 2003                                                                                                                                                                                                                     | 38.62                            | 0.00                           | -53.46                                                                              |
| Severe water stress, no rainfall. Area of agriculture can be reduced so that ID crops can be developed using available water                                                                                             |                                  |                                |                                                                                     |
| 1991                                                                                                                                                                                                                     | 14.84                            | 2.59                           | -64.56                                                                              |
| Severe water stress , 0.45 rainfall . Area of agriculture can be reduced so that ID crops can be developed using available water                                                                                         |                                  |                                |                                                                                     |

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