Modelling the Crop Water Requirement Using CROPWAT: A Case Study of Samrat Ashok Sagar (Halali) Project Command

T.R. NAYAK
Scientist, National Institute of Hydrology, Regional Centre, Bhopal, India
tejramn@yahoo.com

M.K. Choudhary
Assoc. Prof., Maulana Azad National Institute of Technology, Bhopal, India

V.K. Pandram
Research Scholar, Maulana Azad National Institute of Technology, Bhopal, India

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ABSTRACT:

This paper is focuses on analyzing the crop water requirement of Wheat crop using 9 year (2005-2013) average climatic data of Samrat Ashok Sagar reservoir command area in Vidisha district of Madhya Pradesh state, India. CROPWAT & ILWIS are used to estimate Crop water requirement and Area distribution under different canals respectively. Four type of Soils existed in command area are considered for Irrigation scheduling as per their parameter. Study shows that the Crop Water Requirement in the Samrat Ashok Sagar command has been estimated to be 106.50 MCM based on the climatic consideration only and 110.83 MCM as per Climatic with Soil parameter both. At least 16 % less water will be required as compared to the designed crop water requirements of 131.89 MCM for the SAS Project command, if the irrigation scheduling is planned according to CROPWAT model. The savings in irrigation water may be utilised for extension of command area.

1. INTRODUCTION

Water is becoming precious and scarce due to its increasing demand in agriculture and industrial sector. Agriculture being the mainstay of population and exploitation of available water resources to meet the agricultural need requires its scientific management. An important aspect of agricultural planning is to work out requirements of water for crops. The water requirements of crop vary widely from crop to crop and also during the entire crop growth period of individual crop. Thus estimation of crop water requirements considering the crop pattern has been an area which has attracted attention of water resources planners and engineers. The main parameter which is required to be determined for estimating the crop water requirements is crop evapotranspiration (ETo) which when multiplied with the crop factor gives the value of water required by the crop.

1.1 Crop water requirements

Crop water requirements may be defined as “The depth of water consumptively used by a crop with unavoidable irrigation application losses”. The CWR always refers to a crop grown under optimal situation, a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including productiveness and water). The crop thus reaches its full production potential under the given grown atmosphere. The CWR mainly depends on ETo, effect of rainfall, soil characteristics and crop type (FAO, 1984). Ehsani et al. (2012) have worked on potential and actual evapotranspiration, using Penman-Matis method. The result showed that potential evapotranspiration in growing season was 6.16 times greater than the average of actual evapotranspiration. Thimme Gowda et al. (2013) carried out a study for determination of crop evapotranspiration and yield responses to water, CROPWAT model was used. An experiment to study water requirement of maize for under rainfed condition at Dharwad was conducted during kharif season of 2011 in field deep black soil at Main Agricultural Research Station, Dharwad. Diro and Ketema (2009) conducted study on deficit irrigation, conserves water and minimizes adverse effects of surplus irrigation. In this study, the applicability of the CROPWAT model in management of scarcity irrigation was evaluated at Sekota Agricultural Research Centre, Ethiopia.

1.2 Irrigation Scheduling

Irrigation criteria and Irrigation Scheduling are the indicators used to find out the need for irrigation. The common irrigation criteria are soil moisture content and soil moisture tension. Soil moisture content to trigger irrigation depends on the irrigator's goal and scheme. In this case, the goal is to maximize yield. Therefore, the irrigator will try to keep the soil moisture content higher than a critical level (wilting point). If soil moisture falls below this level, the yield may be lower than the maximum potential yield. Thus, irrigation is applied whenever the soil water content level reaches the critical level. In some cases, irrigation scheduling may actually increase irrigation water use, while concurrently increasing crop yield by avoiding critical soil water deficits that reduce Crop yield or by supplying both water and nutrients needed by the crop at a more "optimum" time for the particular crop. In fact, it is more illustrative to separate ET into its components and express the seasonal irrigation requirements. Irrigation scheduling is a technique designed to accurately give water to a crop in a timely fashion (El-Tantawy, et al., 2007). Irrigation scheduling methods are based on two approaches: soil measurements and crop monitoring (Hoffman et al., 1990). However, the use of more efficient technologies often increases, rather than decreases, water consumption (Whittlesey 2003). Improved irrigation scheduling can reduce irrigation costs and increase crop quality. Irrigation scheduling based upon crop water status is more advantageous since crops respond to both the soil and aerial environments (Yazar et al., 1999).

1.3 Objectives of the Study

The primary objective of an irrigation project is to increase the productivity in the command area and therefore by improving the livelihood of the people. The present study deals with the estimation of crop water requirements and irrigation scheduling for command of Samarat Ashok Sagar Reservoir in Vidisha district under variables climatic and rainfall scenarios. It is proposed to develop monthly relationship where all the monthly data considered in the analysis for crop water requirement for the Samarat Ashok Sagar Reservoir Command area. Finally crop and irrigation water requirements and irrigation scheduling have been worked out with the help of CROPWAT model.

2. STUDY AREA

The study is focused on Crop water requirement for deferent Rabi Crops considering meteorological data viz. Rainfall of Samrat Ashok Sagar command area. The Samarat Ashok Sagar Reservoir command area also known as Halali Command area selected for the study located at longitude of 77°30′00" E and Latitude of 23°20′00" N near village Khowa at border of Raisen and Vidisha district in the Madhya Pradesh and this reservoir is about 458 meters above mean sea level. Samarat Ashok Sagar Reservoir is located 45 km away from the Bhopal capital of Madhya Pradesh. Fig. 1 showing the base map of Samrat Ashok Sagar reservoir.

2.1 Climatic & Soil Information of Study Area

2.1.1 ***Rainfall:*** The climate of the study area is sub humid. The average annual rainfall is about 1108 mm.

2.1.2 ***Temperature:*** The temperature of the region varies from maximum 48^0 in the month of June to minimum at freezing point in month of January. Winter temperature varies from 10^0C to 25^0C and summer temperature varies from 25^0C to 42^0C.

2.1.3 ***Wind Variation:*** The direction of the Prevailing wind is generally south- west during period of April to July. It is north – west during September to November During the rest of the period i.e. winter it is generally clear. The wind speed is its peak during the summer season.

2.1.4 ***Mean Relative Humidity:*** The weather is generally dry except during monsoon when it remains sub humid.

2.1.5 ***Rivers & Drainage System:*** Samrat Ashok Sagar command area is situated in a natural drainage system with Halali River a Tributary of the Betwa River. The command area is spread from dam site up to Left bank of Betwa River.

2.1.6 ***Topography and Soil:*** General topography of command area is plain having gentle slopes and some part is terrain. Soils of the Samrat Ashok Sagar Command area fall under the broad group of Clay and loamy soils. The soil code of the soils are 210 for Loamy soil, 379 for Clay soil 1, 399 for Clay soil 2, and 412 for Clay soil 3. The area of soil 379 is higher than other soils distribution under command Samrat Ashok Sagar command located in the Soil Sheet no.2 prepared by National Bureau of Soil Survey and Land Use Planning. The soil map of the study area is shown in fig 3.5. Table 3.3 showing canal command wise soil area distribution and Table 3.4 showing the taxonomy of existing soils an percentage of respective soil under command area.

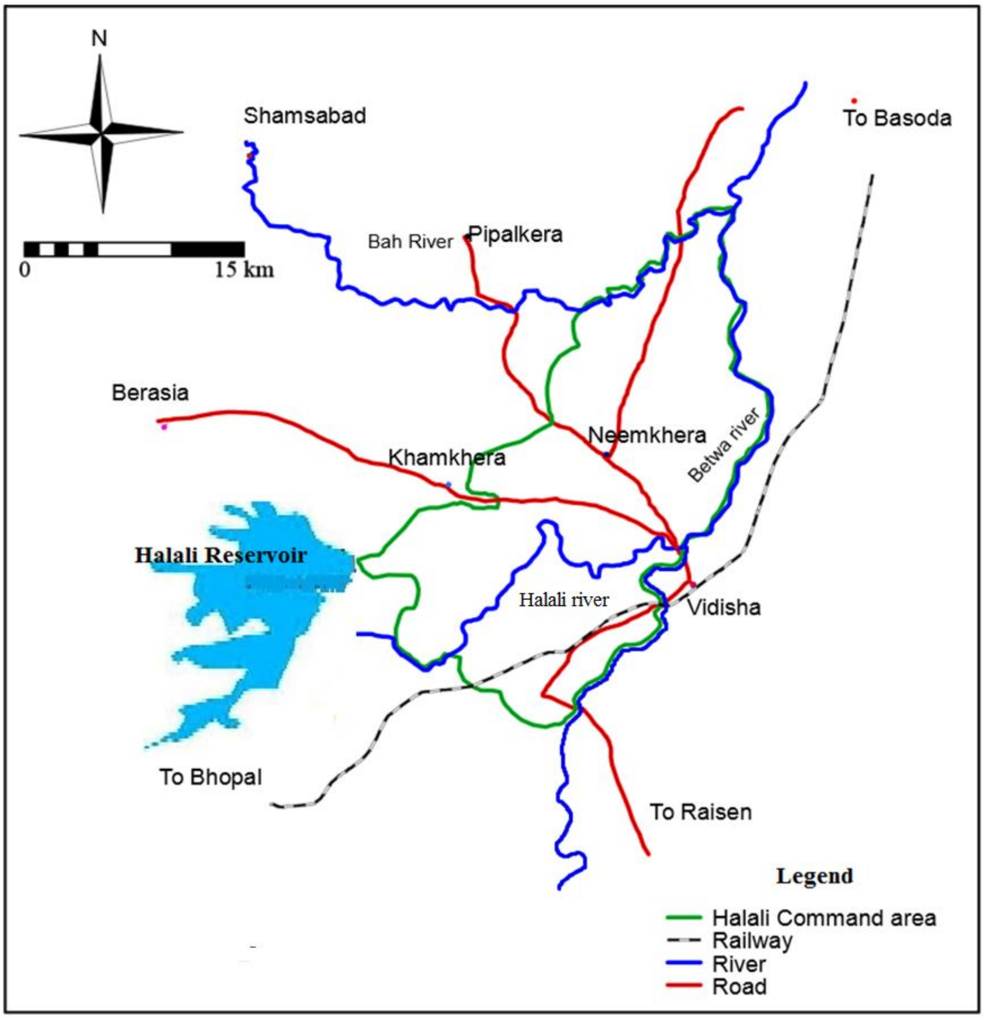

Figure 1: Base map of the Samrat Ashok Sagar Command area

2.2 CWR of Existing Crops as per Dam Authority

For the irrigation under Samrat Ashok Sagar project the Dam authority has been estimated Crop Water Requirement in MCM for existing Rabi crops with the help of corrected penman method. With the help of Back Calculation we have been estimated the Crop water requirement in term of mm where the field efficiency is assume 70% and Canal system conveyance losses are considered 15%.Table 1 showing the Crop Water Requirement of different crops as per whole command area.

Table 1: CWR of Rabi Crops as per Dam authority of Samrat Ashok Sagar Project

CROPS	Area	Total CWR	Total IWR by adding Canal Losses	GIWR	CWR
	(ha.)	(MCM)	(mm)	(mm)	(mm)
Wheat	13155	79.65	605.47	526.50	368.55
Gram & pulses	15378	67.34	437.90	380.78	266.55
Pea	265	01.21	456.60	397.05	277.93
Mustard	1330	05.72	430.08	373.98	261.78
Total	**30128**	**153.92**	**1930.05**	**1678.30**	**1174.81**

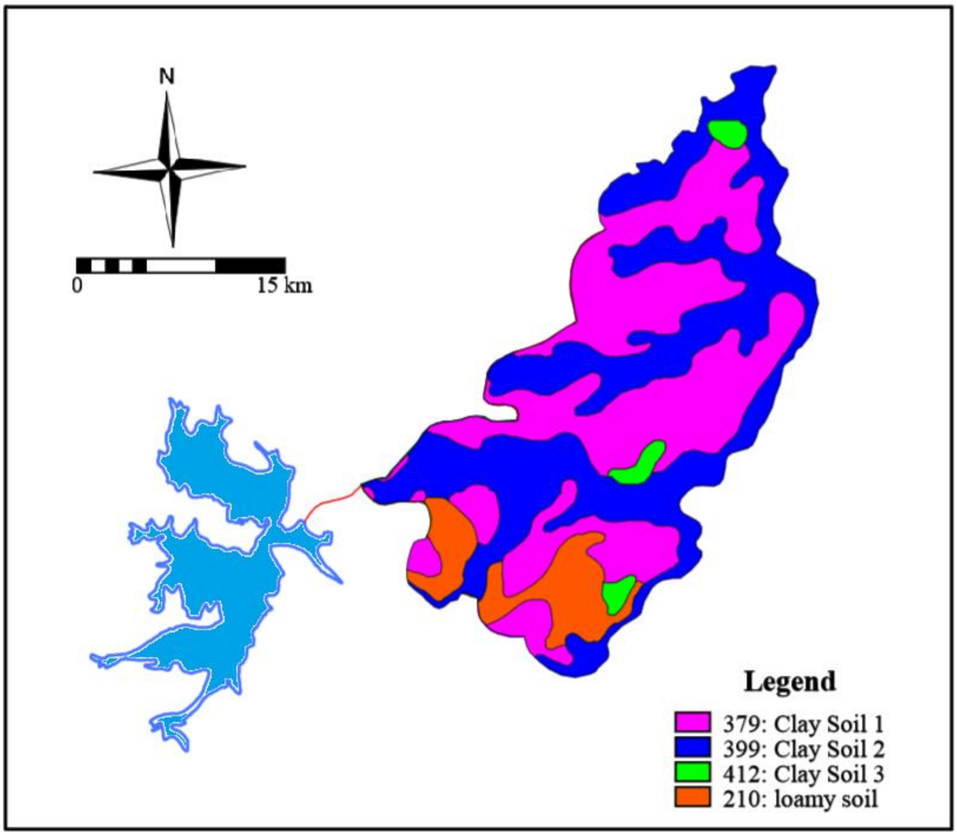

Figure 2: Soil Map of Samrat Ashok Sagar Command area

3. METHODOLOGY

Open source software, the ILWIS GIS has been used for digitizing of study area and canal command area to generate the soil map land use /land cover of the study area and identify the canal command area. The maps created in GIS platform deals with the CROPWAT 8.0 model and their input parameters used for estimation of Crop Water Requirement and Irrigation Scheduling.

3.1 Calculation of Crop Water Requirement

The appropriate design and management of irrigation system and the judicious application of water in the field requires reliable information on consumptive use of various crops grown in the command area. The water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place. The water applied in the field during irrigation acts as a carrier for nutrients to plants and a major part of applied water lost through transpiration with little uses by plants for building tissues. The crop water requirement includes evapotranspiration, application losses and special needs. Application losses include the loss of water during water application. Special needs include water required for land preparation, transplantation and leaching etc. In the present study, CROPWAT 8.0 software has been used for computation of crop and irrigation water requirement.

$$\mathrm{ET_c} = \mathrm{K_c} * \mathrm{ETo} \quad (1)$$

Where,

$\mathrm{ET_c}$ = Crop evapotranspiration
$\mathrm{K_c}$ = Crop coefficient
$\mathrm{ET_0}$ = Reference evapotranspiration

3.2 Calculation of Net Irrigation Requirements

It is important to make a distinction between crop water requirement (CWR) and irrigation requirement (IR). Whereas crop water requirement refers to the water used by crops for cell construction and transpiration, the irrigation requirement is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. If irrigation is the sole source of water supply for the plant, then the irrigation requirement will be at least equal to the crop water requirement, and is generally greater to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the soil, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement. The Net Irrigation Requirement (IRn) does not include losses that are occurring in the process of applying the water,
The net irrigation requirement is derived from the field balance equation:

$$\mathrm{IR_n} = \sum_{t=0}^{T}\left(K_c.ET_0 - P_{eff}\right) \quad (2)$$

Where:

$\mathrm{IR_n}$ = Net irrigation requirement (mm)
$\mathrm{ET_o}$ = Reference Crop evapotranspiration (mm)
P_{eff} = Effective dependable rainfall (mm)
K_c = Crop Coefficient or Factor
T = Total Growing Period of Crop

3.3 Determination of Irrigation Scheduling

Irrigation scheduling is the process of determining the time to irrigate and how much water is to be applied in the each irrigation. In order to compute the irrigation schedules using the CROPWAT model, the detailed information meteorological, crop and soil data. This was done by selecting the options; irrigate at 100% critical depletion, from the irrigation-timing, refill soil to field capacity from irrigation application and irrigation efficiency 70% in scheduling criteria window. In irrigation scheduling for crops the soil moisture balance option was selected to show the status of the soil, the soil moisture changes in the growing season.

The soil water balance aims to evaluate the soil moisture status accounting of all ingoing and outgoing water in the root zone over a defined time step. To express the water content as root zone depletion is useful as it makes the adding and subtracting of losses and gains straightforward as the various parameters of the soil water budget are usually expressed in terms of water depth. In the Schedule module of CROPWAT 8.0, the soil water balance is carried out on a daily basis. As default, the page opens with table format on "Irrigation schedule". To display day-by-day balance, change table format from "Irrigation schedule" into "Daily soil moisture balance".

$$\mathrm{D_r} = \mathrm{D_{r,n-1}} + \mathrm{ET_{c_{adj}}} - \mathrm{P} - \mathrm{I} + (\mathrm{RO} + \mathrm{DP}) \quad (3)$$

Where,

$\mathrm{D_r}$ = Root zone depletion on day n
$\mathrm{D_{r,n-1}}$ = Root zone depletion on day n-1
$\mathrm{ET_{c_{adj}}}$ = Crop evapotranspiration under non-standard conditions on day n

P	= Total rainfall over day n
I	= Net irrigation on day n
RO	= Water loss by runoff from the soil surface on day n
DP	= Water loss by deep percolation on day n

D_r is calculated prior to irrigation application, if any. It is assumed that RO occurs each time P exceeds the Maximum infiltration rate. DP is estimated to occur each time the available soil moisture content in the root zone exceeds Field Capacity (FC). Since precipitation losses are determined through RO and DP, total and not effective precipitation is used in the soil water balance. In the present study, the average climatologically values, crops information and soil data have been used to compute crop water requirement and irrigation scheduling for Samrat Ashok Sagar command.

4. RESULTS AND DISCUSSIONS

4.1 Evapotranspiration from Cropped Area

The average reference evapotranspiration has been computed with the help of CROPWAT 8.0 software developed by FAO using the climatic data viz., Maximum and Minimum Temperature, Relative Humidity, Wind Speed and Sunshine hrs from the year 2003 to 2013. The reference evapotranspiration ET_0 has been estimated Samrat Ashok Sagar Command area. The average daily reference evapotranspiration at Samrat Ashok Sagar Command is 4.28 mm/day. The variation of the monthly ET_0 is given in Fig. 3.

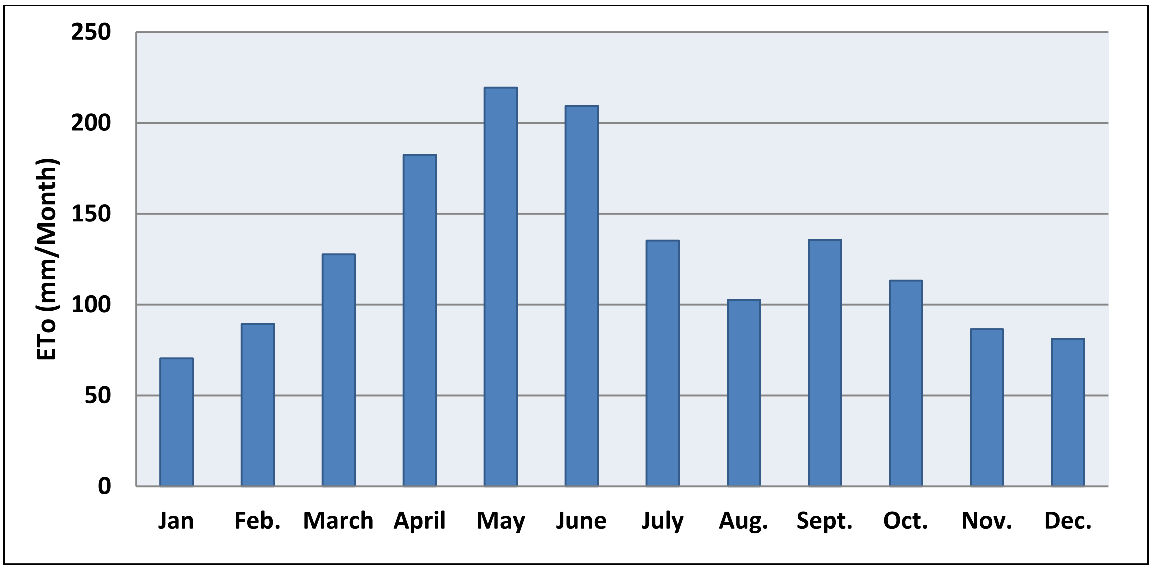

Figure 3: Monthly variation of ETo at Samrat Ashok Sagar Command

4.2 Effective Rainfall

Different methods exist in the CROPWAT 8.0 model, to estimate the effective rainfall. One of the most commonly used methods is the USDA Soil Conservation Service Method. The average monthly effective rainfall of the Samrat Ashok Sagar command is shown in Fig. 4.

4.3 Crop Distribution

The Project Authority has given the distribution of cropped area for the total Samrat Ashok Sagar command area. The cropped area have been further sub-divided according to the area under different branch canals, i.e. Left Bank Canal, Right Bank Canal and Sahodra Branch Canal for computation of water requirements on the basis of climatic consideration. However, for the computation of crop water requirements on the basis of climate and soil type, the area under different crops have been taken in the same ratio as the branch canal command is covered by different soil class. The canal command wise distribution of crops presented in the Table 2.

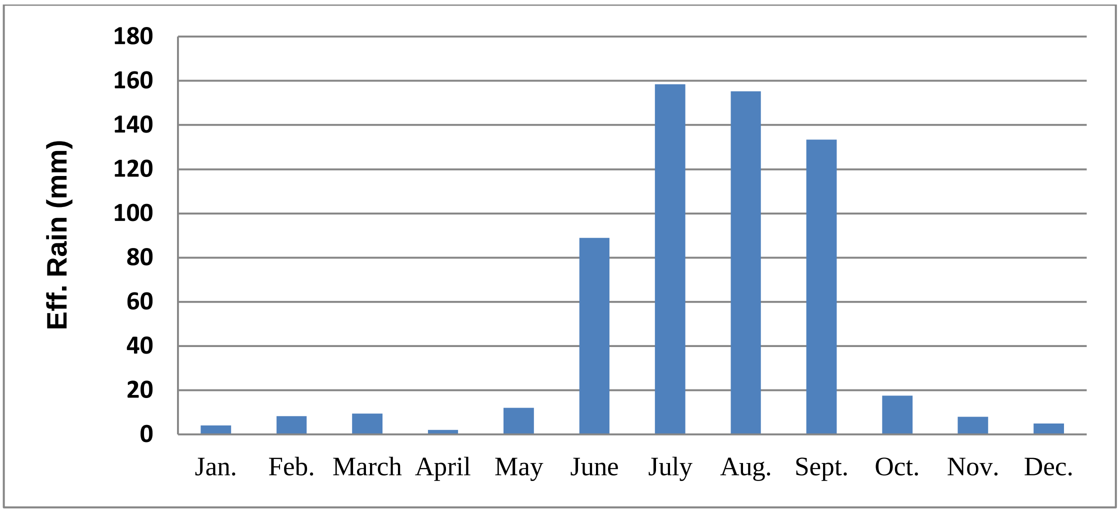

Figure 4: Effective Rainfall distribution of study area

Table 2: Soil-Wise Crop Distribution in the SAS Command (ha)

Canal	Soil Code	Wheat	Gram	Pea	Mustard	Total
LBC	**379**	2156	2521	43	218	**4938**
	399	2019	2360	41	204	**4624**
	412	12	14	00	1	**27**
SBC	**379**	2610.5	3051.6	52.6	263.8	**5978.5**
	399	2185.3	2554.6	44	220.8	**5004.7**
	412	99.6	116.7	2	10.1	**228.4**
RBC	**210**	463.5	542.3	9.3	46.9	**1062**
	379	1185.5	1386.3	23.8	119.9	**2715.5**
	399	1435.2	1677.5	28.9	145	**3286.6**
	412	85.4	99.8	1.7	8.4	**195.3**
Total		**12252**	**14323.8**	**246.3**	**1237.9**	**28060**

4.4 Crop Water Requirement

The crop water requirements for all existing crop have been computed using CROPWAT 8.0 software. All calculation procedures used in CROPWAT 8.0 are based on the FAO guidelines as laid down in the publication No. 56. CROPWAT 8.0 uses Penman-Monteith method for computation of reference crop evapotranspiration (ET0). This method has been selected because it provide values that are very consistent with actual crop water uses data worldwide, as it has been demonstrated through many years of evaluations reported in the scientific literature.

4.4.1 Total Crop Water Requirements followed by SAS Project Authority

The gross crop water requirements followed by the Samrat Ashok Sagar Project authority at the Canal Head required to irrigate the Rabi crop grown in the command area as per design is given at Table 3.

Table 3: Gross Irrigation requirement according to CCA (MCM)

Canal	Net Irrigation Water Requirement (MCM)				
	Wheat	Gram	Pea	Mustard	Total
Left Bank Canal	23.32	19.72	0.35	1.67	**45.07**
Sahodra Branch Canal	27.27	23.06	0.41	1.96	**52.70**
Right Bank Canal	17.65	14.93	0.27	1.27	**34.12**
Grand Total	**68.25**	**57.71**	**1.03**	**4.90**	**131.89**

4.4.2 Canal Command Area Wise Net Irrigation Water Requirement

For computation of Net irrigation water requirements, whole command area has been divided into Canal command area. The Volume basis Net irrigation water requirements for existing cropping pattern has been computed separately by subtracting $\mathbf{P_{eff}}$ from ETo and multiplied by respective areas in the canal command area, The Net Irrigation water requirement on the basis Climatic condition for three canals command area presented in table 3.

Table 3: Net Irrigation requirement according to Climatic parameter (MCM)

Canal	Net Irrigation Water Requirement (MCM)				
	Wheat	Gram	Pea	Mustard	Total
Left Bank Canal	10.59	10.37	0.18	1.01	**22.15**
Sahodra Branch Canal	12.39	12.13	0.21	1.18	**25.91**
Right Bank Canal	08.02	7.86	0.13	0.77	**16.78**
Grand Total					**64.84**

4.4.3 Canal Command Wise Gross Irrigation Water Requirement

By assuming 70% field efficiency, Gross Irrigation water requirement has been calculated and further consider Losses due to Conveyance in Canal system 15% added to the Gross water requirement for existing crops in each canal command area. Volume basis (MCM) Gross Irrigation requirement is represented in Table 4.

Table 4: Gross Irrigation requirement according to Climatic parameter (MCM)

Command area	Wheat	Gram	Pea	Mustard	Total
Left Bank Canal	17.40	17.04	0.29	1.67	**36.40**
Sahodra Branch Canal	20.34	19.93	0.33	1.94	**42.55**
Right Bank Canal	13.18	12.90	0.22	1.25	**27.55**
Total	**50.92**	**49.88**	**0.84**	**4.86**	**106.50**

4.4.4 Gross Irrigation requirement according to Climatic and Soil parameter

CROPWAT calculate the net irrigation water requirement of crops for irrigation scheduling with respect to soil parameter and climatic parameter which we have placed as input. CROPWAT takes field irrigation efficiency 70% as its default value to calculate Gross Irrigation water. Table 5 showing the gross irrigation water requirement as per the climatic with soil parameter.

Table 5: Climate and soil based Canal Wise Gross Irrigation Water Requirements (MCM)

Command area	Wheat	Gram	Pea	Mustard	Total
Left Bank Canal	20.62	16.91	0.29	1.73	**39.54**
Sahodra Branch Canal	21.21	19.79	0.33	2.02	**43.36**
Right Bank Canal	13.78	12.64	0.21	1.31	**27.93**
Total	**55.60**	**49.34**	**0.83**	**5.06**	**110.83**

4.5 Irrigation Scheduling

Irrigation was scheduled on the basis of Climatic data, rainfall, crops and soil data using the CROPWAT model 8.0. The scheduling was done by taking the Net irrigation water requirement for different crops of Rabi season under different soil mapping unit and the scheduling was done for each canal command. The irrigation scheduling has been calculated as per Samrat Ashok Sagar different branch canal. Fig. 5 shows the Irrigation scheduling graph on the basis of soil type for loamy soil. Similarly, irrigation scheduling has been obtained for other soil type also.

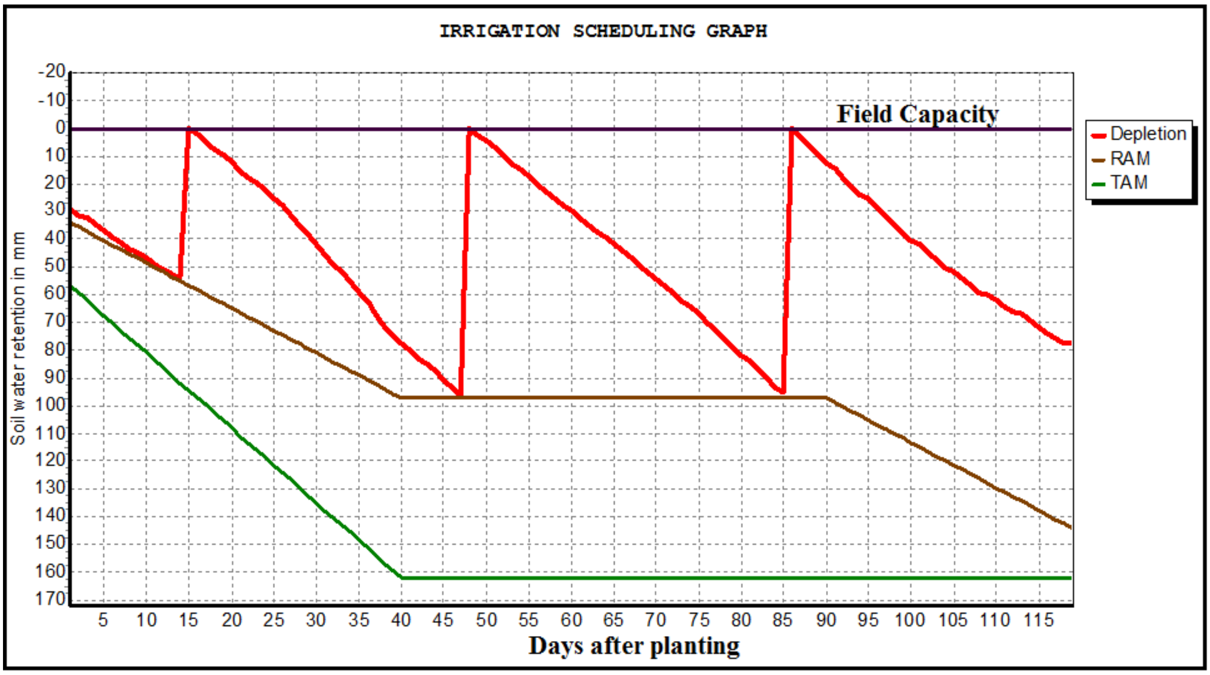

Figure 5: Irrigation scheduling graph of Wheat in Loamy soil (210)

4.6 Discussion of Results

I. The total irrigation water requirement estimated by Dam Authority is 131.89 MCM whereas the total irrigation water requirement estimated by CROPWAT is 106.50 MCM as per the climatic consideration only and 110.83 MCM as per Climatic with Soil parameter both.

II. There is the difference of **25.39** MCM **(19.3%)** and **21.06** MCM **(16.0 %)** between the irrigation demand taken up by the dam authority and estimated by CROPWAT by considering climatic condition only and by considering climate and soil type both.

III. The difference in irrigation water requirement may be considered as excess available water in the reservoir, which may be utilized for other seasonal crops cultivation or expansion of existing canal command.

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