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PROJECT REPORT

VALIDATION OF CONSUMPTIVE USE OF WATER (ETo) AND CALCULATION OF DISCHARGE OF GREATER THAL CANAL

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This to certify that

the BE Civil Engineering Project titled

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DEDICATION

Dedicated to our beloved Parents and Teachers, whose prayers and guidance have always been source of inspiration and motivation.

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Abstract

The Greater Thal Canal command area is situated between River Indus and Jhelum in Doaba Sind Saghar. It is a vast desert land sprawling over 0.7 million hectares. Indus Basin Irrigation System (IBIS) is one of the largest irrigation systems in the world. One of the most important issues is the loss of over 60% water during conveyance and application in the fields. Over-irrigation is a common practice due to lack of knowledge about Irrigation scheduling (when to apply and how much to apply irrigation water?). The knowledge of crop water requirement/evapotranspiration is important for devising proper irrigation scheduling. The climate of the area is arid with an average annual rainfall of 295 millimeters and evapotranspiration of 1769 mm, which is almost 6 times the rainfall. During Kharif the evapotranspiration is very high making it almost impossible to farm without irrigation facility. Provision of a regulated irrigation system is essential for successful farming in the command area. GTC is planned to command 703,858 hectares (1,739,233 acres) of extensive desert land. The Project command area will be divided in three phases. Phase I is the Greater Thal Main canal and Mankera Branch canal. These canals have been constructed and commissioned. Their share of water is being released since the last several years, but potential benefits are not yet achieved due to incomplete distribution system and command area development. It is envisaged that the cropping pattern would improve, and intensity and productivity would increase with the provision of irrigation due to project interventions. The design discharge of GTC is 8,500 Cusec (241 M3/s), while water requirements have been overestimated up to 9,670 Cusec (274 M3/s) ignoring the capacity of the Canal and quantity of water availability. The cropping intensity proposed with Project is much higher than the allocated water could sustain. To begin with the design the first step is to calculate the crop water requirement which dictate the distribution and discharge of the channels. The crop water requirements are computed to plan irrigated agriculture development according to the water availability and design irrigation distribution network for the project command area. Climatic data representing the climatic conditions prevailing in the command area is a basic requirement for estimating crop water requirements. There is no climatic station in the project command area. However, PMD station Sargodha, Faisalabad and PMD Station Dera Ismail Khan have been studied to better represent the climate of the Project command area. The requisite climatic data of the representative meteorological stations Faisalabad and Multan for 30 years (1981-2010) was obtained from the Regional Metrological Office Lahore. However, FAO has recommended the Penman – Monteith method which yields better results over other methods. Therefore, CLIMWAT – 8 is used to extract the climatic data of last 30 years, tools have been used to calculate the evapotranspiration and effective precipitation and it is validated it against the data of PMD, PMO Lahore and Irrigation Deparrtment of Lahore.

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1. Introduction

1.1. General

1. The Greater Thal Canal command area is situated between River Indus and Jhelum in Doaba Sind Saghar. It is a vast desert land sprawling over 0.7 million hectares. The climate of the area is arid with an average annual rainfall of 295 millimeters and evapotranspiration of 1769 mm, which is almost 6 times the rainfall. During Kharif the evapotranspiration is very high making it almost impossible to farm without irrigation facility. Presently farming depends on groundwater growing millet, guar seed, fodders, cotton and orchards at very low cropping intensities during Kharif due to the high cost of energy for operating tube wells. During Rabi, Gram occupies almost 60% of the command area under rainfed conditions but the yields are very low due to inconsistent rains. Wheat is grown for home consumption at a very low intensity as the cost of tube well irrigation is not affordable.

2. Provision of a regulated irrigation system is essential for successful farming in the command area. GTC is planned to command 703,858 hectares (1,739,233 acres) of extensive desert land. It is envisaged that the cropping pattern would improve, and intensity and productivity would increase with the provision of irrigation due to project interventions. The current scant human settlements and associated businesses in the deserted land will flourish, providing livelihood to local population as well as encouraging absentee landlord to stay there and establish profitable farming enterprises. The enhanced agriculture production will increase the farm income and improve the socioeconomic condition of the beneficiary farming community. The development of the Project would contribute to the economy of the province and the country at large.

3. The Project command area is be divided in three phases. Phase I is the Greater Thal Main canal and Mankera Branch canal. These canals have been constructed and commissioned. Their share of water is being released since the last several years, but potential benefits are not yet achieved due to incomplete distribution system and command area development.

4. Phase II is the command area of the proposed Chaubara Branch Canal. Agriculture input output data has been updated and the results indicated that construction of Chaubara BC and its distribution system coupled with command area development is economically feasible. Similarly, existing agriculture in Phase III constituting the command areas of Dhingana, Mehmood and Nurpur branch canals.

1.2. Problem Statement

5. GTC is the backbone of South Punjab province irrigation system, it is part of the WAPDA Vision 2025. Indus Basin Irrigation System (IBIS) is one of the largest irrigation systems in the world. One of the most important issues is the loss of over 60% water during conveyance and application in the fields. Over-irrigation is a common practice due to lack of knowledge about Irrigation scheduling (when to apply and how much to apply irrigation water?). The knowledge of crop water requirement/evapotranspiration is important for devising proper irrigation scheduling. Therefore, this loss of water can be met by recalculation of crop water requirement (consumptive use of water) with latest data from 3 neighboring PMD Stations mapping into CROPWAT – 8 and CLIMWAT – 8 software and validating it against the previous study conducted by joint of venture of M/s NESPAK and WAPDA in 2007.

1.3. Review of the Previous Studies

6. WAPDA in 1981 to 1983 classified the soils of the project area into four textural groups namely coarse, moderately coarse, medium and moderately fine which covered 19.1, 76.0, 4.7 and 0.2 percent area respectively. The Consultants (Joint Venture of NESPAK & NDC) carried out field investigations like infiltration and hydraulic conductivity studies, soil moisture retention, surface salinity and textural classifications in 1993. They also conducted salinity survey using aerial photographs of 1976 in 1981 to 1983. According to salinity survey, all the area was non-saline and ECe of surface layer was less than 4 dS/m at 25°C. The last detailed studies for the Greater Thal Canal completed in March 2007 by a joint venture of M/s NESPAK, NDC, ACE, Barqaab and EGC have been reviewed. The studies applied agriculture data for the years 1995-2000 which is very old (almost 20 years) and must be updated and the results reviewed accordingly. Crops like Potatoes and Melons are Rabi crop while the water supply is only for Kharif. The source of irrigation for these crops is not mentioned in the studies. Kharif fodders proposed at very high intensity of 8% on a CCA of 703,858 ha, may not be disposable in the market. The design discharge of GTC is 8,500 Cusec (241 M3/s), while water requirements have been overestimated up to 9,670 Cusec (274 M3/s) ignoring the capacity of the Canal and quantity of water availability. The cropping intensity proposed with Project is much higher than the allocated water could sustain. No support from the conjunctive groundwater is sought to meet shortages during the short supplies from the source. In view of these facts, it is essential to update the basic data and review the Project planning with latest water availability and technical procedures.

7. The recently prepared PC-1 of Chuabara Branch Canal by GTC Consultants July 2019 (updated in December 2019) has used the same old (1995-2000) agriculture data as a basis. However, the same data will be processed in CLIMWAT – 8 and CROPWAT – 8 software to obtain quick and better results as recommended by FAO.

8. Soil Survey of Pakistan, Water and Power Development Authority, Directorate of Land Reclamation Punjab and M/S NESPAK in collaboration with NDC had studied the soils of the project area in previous years. Their findings are briefed below:

    a. Soil Survey of Pakistan in 1968 & 1982 studied the soils at reconnaissance level with the intensity of 2 augerholes per sq. miles. and identified eleven (11) soil associations/ complexes in the project area. The textural break down was extracted from the associations/ complexes which showed a coverage of sandy soils 85 percent, loamy soils 13 percent and clayey soils 2 percent of the area.

    b. The Directorate of Land Reclamation Punjab in 1970 also investigated the soils at reconnaissance level by exposing 47 profiles representing the whole project area. The coarse textured soils cover 63.4 percent, moderately coarse 34.1 percent and medium 2.5 percent.

1.4. Approach and Methodology

1.4.1. Objectives

9. The objective of the project is to validate the consumptive use of water of Greater Thal Canal with latest data collected from CLIMWAT – 8 and CROPWAT – 8. The Penman – Monteith method with FAO recommended software i-e CLIMWAT-8 and CROPWAT have been used to plot the calculated data and validate against the the data of Punjab Irrigation Department.

1.4.2. Planning Approach

10. Understand the process of Evapotranspiration and the factors affecting the process. Since the data for previous studies was too old, so the latest data from CLIMWAT – 8 and CROPWAT – 8 was collected and processed. The CLIMWAT-8 was used to gather the latest data from 3 adjacent MET Office Station. After obtaining this data it was plotted against the data of PMD and Punjab Irrigation Department. Steps of calculating the requirements are as following:-

    a. Collection climatic data of 3 neighboring PMD stations from CLIMWAT – 8
    b. Calculation of Reference Evapotranspiration (ETo) from CROPWAT – 8
    c. Calculation of average monthly Effective precipitation from CROPWAT – 8
    d. Determination of crop irrigation requirements (CIR)
    e. Validating ETo and effective Precipitation against the Punjab Irrigation Department data.

1.4.3. Project Command Area

11. Greater Thal Canal (GTC) command area encompasses a vast extensive arid land area as detailed in the following Table 1.

Table 1 GTC Project Sectors and Command Areas (CCA)

Canal Area	Design Discharges Cusec	CCA (Acre)	CCA (Hectare)
Phase-I			
Greater Thal Main Canal	8,500	98,753	39,965
Mankera Branch Canal	1,215	257,029	104,018
Total Phase-I		**355,782**	**143,983**

Phase-II **Chaubara Branch Canal**	1,463	**294,110**	**119,025**
Phase-III			
Dhingana	3,879	496,501	200,931
Mehmood	1,480	284,916	115,304
Nurpur	1,500	307,924	124,615
Total Phase-III		**1,089,341**	**440,850**
GTC Grand Total		**1,739,233**	**703,858**

2. Agriculture Development with Project GTC

12. The project aims at provision of water for irrigation during Kharif, beginning April to end September through the Greater Thal Canal System. The canal supplies will be applied to improve the cropping pattern, increase cropping intensity and yields, resulting in an increase in farm income. This in turn will provide food security and improve the socio-economic conditions of the populace in the area. The incremental agricultural production with project implementation would contribute to the provincial and national economy. Future planning of agriculture development has been based on volume of irrigation water expected to be available with project interventions, crop water requirements, the size of the irrigable command area, soil crop suitability, agroclimatic conditions, food and fibre requirements, marketing infrastructure, socio economic conditions, availability of agricultural support services and irrigated agriculture practiced in the adjacent irrigated area. Standard procedures and plans of agriculture development have been applied as discussed in the following sections of this report.

2.1. Cropping Pattern and Intensities

13. The most important measure of agriculture development is the cropping pattern and intensities. Cropping patterns and intensities for the project are formulated in consonance with the following facts about the project command area.

    a. Quantum of irrigation water availability with project interventions
    b. Crop water requirements and irrigation efficiency of the distribution systems
    c. Agroclimatic conditions prevailing in the command area
    d. Crop suitability of the project soils
    e. Cropping patterns already established in the command area
    f. Cropping pattern and intensities achieved in adjacent irrigated commands
    g. Food and fiber requirements of the local populace

2.2. Justification of Selection of Crops

14. The crops selected for the proposed cropping pattern 'With' Project are already grown in the command area and adjacent irrigated areas. The selected crops are required for local food security and there is demand for surplus in the local as well as big city markets. The farmers are already familiar with these crops and the Department of Agriculture will also be providing extension services for the cultivation of these crops to maximize water productivity as the canal water becomes available with Project interventions.

2.3. Justification of Selection of Cropping Intensities

15. The choice of crops has been briefly explained above and is dependent on agroclimatic and socio-economic factors described earlier. Cropping intensity is also closely related with those factors but quantum of water available for irrigation and the size of the command area are the main factors determining cropping intensities. The agronomic expertise and knowledge of agriculture development is also a basic requirement for evolving a balanced future cropping pattern and intensities for cost recovery and sustainable future farming with project. CPI with and without project for Phase-I, Phase-II, Phase-III and overall, for GTC whole command area are respectively presented in Table 2

Table 2 Cropping Pattern and Intensities 'With' and 'Without' ProjectGTC Canal System All Three Phases Total CCA Hectare) =703,858

No.	Crops	Intensities as % of Command Area	
		Without Project	With Project
Kharif Season			
1	Millet	6.2	6.8
2	Kharif Fodders	0.9	2.0
3	Melons	0.0	2.0
4	Groundnut	0.0	1.0
5	Sesame	0.1	3.0
6	Mung	0.8	4.2
7	Guar seed	2.7	2.9
8	Cotton	1.9	3.8
Kharif Total		**12.6**	**25.7**
Rabi Season			
9	Wheat	14.8	14.8
10	Gram	53.7	53.7
11	Rabi Fodder	0.1	0.1
12	Rabi Oilseeds	0.3	0.3
13	Onion	0.0	2.3
14	Turnips	0.0	0.0
15	Potato	0.0	0.0
16	Peas	0.1	0.1

GTC Canal System All Three Phases Total CCA Hectare) = 703,858

No.	Crops	Intensities as % of Command Area	
		Without Project	With Project
Kharif Season			
Rabi Total		**69.0**	**71.3**
	Perennial Crops		
17	Lucerne Alfalfa	0.6	2.0
18	Dates	0.1	1.0
19	Oranges	0.4	2.0
20	Orchard HEIS	0.0	0.4
21	Forest	0.1	1.6
Perennial Total		**1.2**	**7.0**
Annual Total		**82.8**	**104.0**

16. The average existing Kharif cropping intensity in the whole GTC command area has been estimated to be 13.8%, which is assumed to continue without project as the existing farming practices are not going to improve without project interventions. With Project intervention due to canal water supplies, the cropping intensity has been estimated to reach 35% (42% with Perennial counted double). The available canal water can sustain only this cropping intensity in Kharif. However, in view of increased farm income emphasis has been laid on cash crops such as Kharif pulses (Mung) and oilseeds (Sesame) which are common in the adjacent irrigated area or even grown under groundwater irrigation. Orchards are perennials but are a popular enterprise in that area. There is a trend in the field to grow orchards with tube well irrigation in the absence of canal water. Therefore, the existing orchard will benefit from canal water in Kharif, and farmers will be encouraged to increase the intensity of fruit crops.

17. Rabi crops have been included in the with and without project scenarios, with the same input and output values to signify the complete existing or without Project farming practice and agriculture production in project areas. There would be insignificant effect of 5-month canal water supplies on Rabi agriculture. Anyway, it should be studied and quantified as a simple assumption would be misleading, therefore the safest way is to put Rabi crops in both sides of the balance, the With and the Without Project.

2.4. Cropped Area 'With' or Without' Project

18. Cropped area computed against the CPI designed 'With' Project conditions has been displayed in comparison with the 'Without' Project scenario for all the Phases and presented in Table 3 for GTC Whole command respectively. Incremental cropped with project interventions is also computed.

Table 3 Cropped Area ‘With’ and Without Project Interventions

GTC Canal System All Three Phases Total CCA (Hectare) = 703,858

No.	Crops	Cropped Area (Hectare)		
		Without Project	With Project	Incremental
Kharif Season				
1	Millet	43822	47581	3758
2	Kharif Fodders	6155	14077	7922
3	Melons	0	14077	14077
4	Groundnut	59	7039	6979
5	Sesame	699	21116	20416
6	Mung	5774	29594	23820
7	Guar seed	19141	20351	1210
8	Cotton	13284	26964	13680
Kharif Total		**88,936**	**180,799**	**91,863**
Rabi Season				
9	Wheat	104060	104060	0
10	Gram	377916	377916	0
11	Rabi Fodder	1012	1012	0
12	Rabi Oilseeds	1918	1918	0
13	Onion	0	16281	16281
14	Turnips	0	0	0
15	Potato	0	0	0
16	Peas	814	814	0
Rabi Total		**485,719**	**502,001**	**16,281**
Perennial Crops				
17	Lucerne Alfalfa	4108	14077	9969
18	Dates	418	7039	6620
19	Oranges	2923	14077	11154
20	Orchard HEIS	0	2991	2991
21	Forest	699	11086	10387
Perennial Total		**8148**	**49270**	**41,122**
Annual Total		**582,803**	**732,070**	**149,267**

19. It may be noted from the data in Table 3 that an incremental area of 149,267 hectares will be cropped with provision of canal water with Project implementation. The bulk of increase is in the Kharif season as the project is mainly for Kharif supplies. However, perennial crops, mainly fruit, have been given due attention to increase farm income.

2.5. Crop Yields and Production “With” Project

20. The effects of enhanced irrigation water supply with Project interventions have been applied primarily on improving cropping pattern and increasing cropping intensities in the command area. The yields are slightly increased due to better quality of canal water improved farming practices as a result of better agriculture support services. The yields have been applied to compute agriculture production with and without project of various crops with Project interventions. The crop yields have been staggered by year of development and shared with the Project Economist for analysis.

Table 4 Crop Production 'With' and 'Without' Project Interventions

GTC Canal System All Phases Total CCA (Hectare) = 703,858

No.	Crops	Production in Tons		
		Without Project	With Project	With Project
Kharif Season				
1	Millet	70,707	77,611	6,904
2	Kharif Fodders	70,590	170,513	99,923
3	Melons	-	234,146	234,146
4	Groundnut	53	6,493	6,440
5	Sesame	714	22,011	21,298
6	Mung	6,334	33,086	26,752
7	Guar seed	13,724	14,792	1,068
8	Cotton	21,396	44,029	22,633
Kharif Total		**183,518**	**602,682**	**419,164**
Rabi Season				
9	Wheat	278,244	278,244	-
10	Gram	231,590	231,590	-
11	Rabi Fodder	25,151	25,151	-
12	Rabi Oilseeds	2,226	2,226	-
13	Onion	-	287,499	287,499
14	Turnips	-	-	-
15	Potato	-	-	-
16	Peas	3,697	3,805	108
Rabi Total		**540,909**	**828,515**	**287,607**
Perennial Crops				
17	Lucerne Alfalfa	169,667	638,562	468,894
18	Dates	2,736	45,547	42,811
19	Oranges	29,484	146,708	117,224
20	Orchard HEIS	-	39,241	39,241
21	Forest	21,500	496,108	474,608
Perennial Total		**223,387**	**1,366,166**	**1,142,779**
Annual Total		**947,813**	**2,797,363**	**1,849,550**

3. Introduction to Evapotranspiration

21. The concept of reference crop evapotranspiration is discussed in this chapter. The factors that influence evapotranspiration, as well as the units in which it is usually stated and how it can be calculated.

3.1. Evapotranspiration Process

22. Evapotranspiration is the combination of two processes by which the water is lost from the soil surface by evaporation and from the crop through transpiration.

3.2. Evapotranspiration

23. Evaporation and transpiration occur at the same time, and it is difficult to discriminate between the two. Evaporation from a cropped soil is mostly governed by the fraction of solar radiation reaching the soil surface, aside from water availability in the topsoil.

3.3. Factors Affecting Evapotranspiration

3.3.1. Weather Parameters

24. The evapotranspiration from a standardised vegetated surface is represented by the reference crop evapotranspiration. The reference crop evapotranspiration represents the atmosphere's evaporation power (ETo). Radiation, air temperature, humidity, and wind speed are the main meteorological variables that influence evapotranspiration. Several methods for calculating the evaporation rate from these characteristics have been devised.

3.3.2. Crop Factors

25. Crop evapotranspiration under standard conditions (ETc) refers to the evaporating demand from crops produced in wide fields with enough soil moisture, good management, and good environmental conditions, and which reach full production under the given climatic parameters. When calculating evapotranspiration from crops produced in vast, well-managed fields, consider the crop type, variety, and growth stage.

3.3.3. Management and Environmental Conditions

26. Soil salinity, low land fertility, restricted fertiliser application, the existence of hard or impenetrable soil layers, lack of disease and insect control, and poor soil management can all impede crop development and reduce evapotranspiration. Ground cover, plant density, and soil water content are also aspects to consider when calculating ET.

3.4. Determining the Evapotranspiration

3.4.1. ETo Measurement

27. Evapotranspiration is difficult to quantify. To calculate evapotranspiration, certain instruments and precise measurements of several physical parameters or the soil water balance in lysimeters are necessary. The procedures are frequently costly, require high levels of measurement precision, and can only be effectively utilised by well-trained research professionals. Although the approaches are not suitable for regular measurements, they are useful for evaluating ET estimations acquired through more indirect means.

3.4.2. Lysimeter

28. Lysimeters demand that the plants inside and immediately outside the lysimeter be exactly matched (same height and leaf area index). This condition has typically been ignored in the majority of lysimeter research, resulting in significantly erroneous and unrepresentative ETc and Kc results. The different variables in the soil water balance equation can be estimated with higher accuracy by separating the crop root zone from its surroundings and regulating the difficult-to-measure processes. This is done in lysimeters, which are separate tanks filled with either disturbed or undisturbed soil where the crop grows. Evapotranspiration may be measured with an accuracy of a few hundredths of a millimetre in precision weighing lysimeters, where the water loss is directly recorded by the change in mass, and tiny time periods such as an hour can be considered. In non-weighing lysimeters, evapotranspiration is calculated by subtracting the drainage water collected at the bottom of the lysimeters from the total water intake for a specific time period.

3.4.3. ET computed from meteorological data

29. Since reliable field measurements are difficult to come by, ET is frequently calculated using meteorological data. For estimating crop or reference crop evapotranspiration from meteorological data, a significant variety of empirical or semi-empirical equations have been devised. Some of the approaches are only applicable in certain climatic and agronomic settings, and they cannot be used in situations other than those for which they were designed.

4. FAO Penman – Monteith Method

30. The user is introduced to the necessity to standardise one technique for computing reference evapotranspiration (ETo) from meteorological data in this chapter. For estimating reference evapotranspiration, the FAO Penman-Monteith method is suggested as the only ETo approach. This chapter describes the method, its derivation, the needed meteorological data, and the associated definition of the reference surface.

4.1. Need for a standard ET_o method

31. Various scientists and professionals throughout the world have created a vast variety of empirical ways to estimate evapotranspiration from various meteorological factors during the last 50 years. Relationships were frequently subjected to stringent local calibrations, and their worldwide validity was shown to be restricted. Testing the techniques' accuracy under new conditions is time-consuming and expensive, yet evapotranspiration data is commonly needed on short notice for project planning or irrigation schedule design. To satisfy this demand, FAO Irrigation and Drainage Paper No. 24 'Crop water requirements' was prepared and released. Four approaches for calculating reference crop evapotranspiration (ETo) were offered to suit users with varying data availability: the Blaney-Criddle, radiation, modified Penman, and pan evaporation methods. In comparison to a live grass reference crop, the modified Penman approach was thought to provide the best results with the least amount of error. Depending on the placement of the pan, it was thought that the pan technique would provide appropriate estimations. For places where available meteorological data includes observed air temperature and sunlight, cloudiness or radiation but not measurable wind speed and air humidity, the radiation approach was proposed. Finally, the article recommended using the Blaney-Criddle technique in places where the only meteorological data available is for air temperature.

32. ETo calculating climatic techniques were all calibrated for ten-day or monthly estimates, not daily or hourly computations. For intervals of one month or more, the Blaney-Criddle approach was advised. It was proposed that calculations using the pan approach be done for periods of 10 days or more. Users have not always adhered to these guidelines, and computations have frequently been performed on daily time intervals.

33. The findings support the modified Penman's overestimation in FAO Irrigation and Drainage Paper No. 24, as well as the varying performance of the various systems based on their adaptation to local conditions. Following is a summary of the comparative studies:

    a. To produce good results, the Penman techniques may need local calibration of the wind function.

    b. Radiation approaches function well in humid climates with a small aerodynamic term, while performance in arid regions is inconsistent and tends to underestimate evapotranspiration.

    c. Temperature approaches are still empirical, requiring local calibration to produce acceptable results. The 1985 Hargreaves approach, which has produced good ETo findings with worldwide validity, is one probable exception.

d. The difficulties of estimating crop evapotranspiration from open water evaporation are abundantly seen in pan evapotranspiration approaches. The approaches are vulnerable to the microclimatic circumstances in which the pans operate, as well as the rigor with which the station is maintained. Their performance is inconsistent.

e. Both ASCE and European investigations have demonstrated the Penman-Monteith approach's generally accurate and consistent performance in both arid and wet settings.

34. A comparison of the performance of the various calculation techniques demonstrates the necessity for a standard approach for computing ETo. As the only standard approach, the FAO Penman-Monteith method is suggested. It is a method that has a high probability of successfully forecasting ETo in a wide variety of locales and climates, and it may be used in data-limited scenarios. It is no longer recommended to utilise previous FAO or other reference ET techniques.

4.1.1. Data

35. For daily, weekly, ten-day, or monthly computations, the FAO Penman-Monteith equation requires air temperature, humidity, radiation, and wind speed data in addition to the site location. It's critical to double-check the units in which weather data is reported.

4.1.1.1. Location

36. The location's elevation above sea level (m) and latitude (degrees north or south) should be supplied. These data are required to update various weather parameters for the local average value of air pressure (a function of the site elevation above mean sea level) and, in some situations, daylight hours (N). The latitude is given in radians (decimal degrees times p /180) in the calculation techniques for Ra and N).

37. The northern hemisphere is given a positive value, whereas the southern hemisphere is given a negative value.

4.1.1.2. Temperature

38. The (average) daily maximum and lowest air temperatures are required in degrees Celsius (°C). The calculations can still be done if just (average) mean daily temperatures are provided, but due to the non-linearity of the saturation vapour pressure - temperature connection, ETo will most likely be underestimated. The saturation vapour pressure is lower when mean air temperature is used instead of maximum and lowest air temperatures, resulting in a smaller vapour pressure differential (es - ea) and a lower reference evapotranspiration estimate.

4.1.1.3. Humidity

39. Determine the (average) daily actual vapour pressure, ea, in kilopascals (kPa). If real vapour pressure is not known, it can be calculated using maximum and minimum relative humidity (percent), psychrometric data (dry and wet bulb temperatures in degrees Celsius), or dewpoint temperature (degrees Celsius).

4.1.1.4. Radiation

40. It is necessary to calculate the (average) daily net radiation in megajoules per square metre per day (MJ/ m2/ day1). These figures aren't widely accessible, but they may be calculated using (average) shortwave radiation recorded using a pyranometer or the (average) daily real length of strong sunlight (hours per day) measured with a (Campbell-Stokes) sunshine recorder.

4.1.1.5. Wind Speed

41. The (average) daily wind speed recorded at 2 m above ground level in metres per second (m/s) is required. Because wind speeds reported at different heights above the soil surface varies, it's critical to double-check the height at which the wind speed is measured. The wind speed is measured at a standard height of 2 metres.

5. Crop Water and Gross Irrigation Requirements for the Project

5.1. Crop Irrigation Requirements (CIR)

42. The crop water requirements are computed to plan irrigated agriculture development according to the water availability and design irrigation distribution network for the project command area. Climatic data representing the climatic conditions prevailing in the command area is a basic requirement for estimating crop water requirements. There is no climatic station in the project command area. However, PMD stations Faisalabad, Sargodha and DI Khan have been studied and their average is taken to better represent the climate of the Project command area. The climatic parameters required for computation of ETo are listed below:
    a. Maximum daily Temperatures
    b. Minimum daily Temperature
    c. Relative Humidity %
    d. Wind Speed
    e. Sunshine Hours
    f. Rainfall

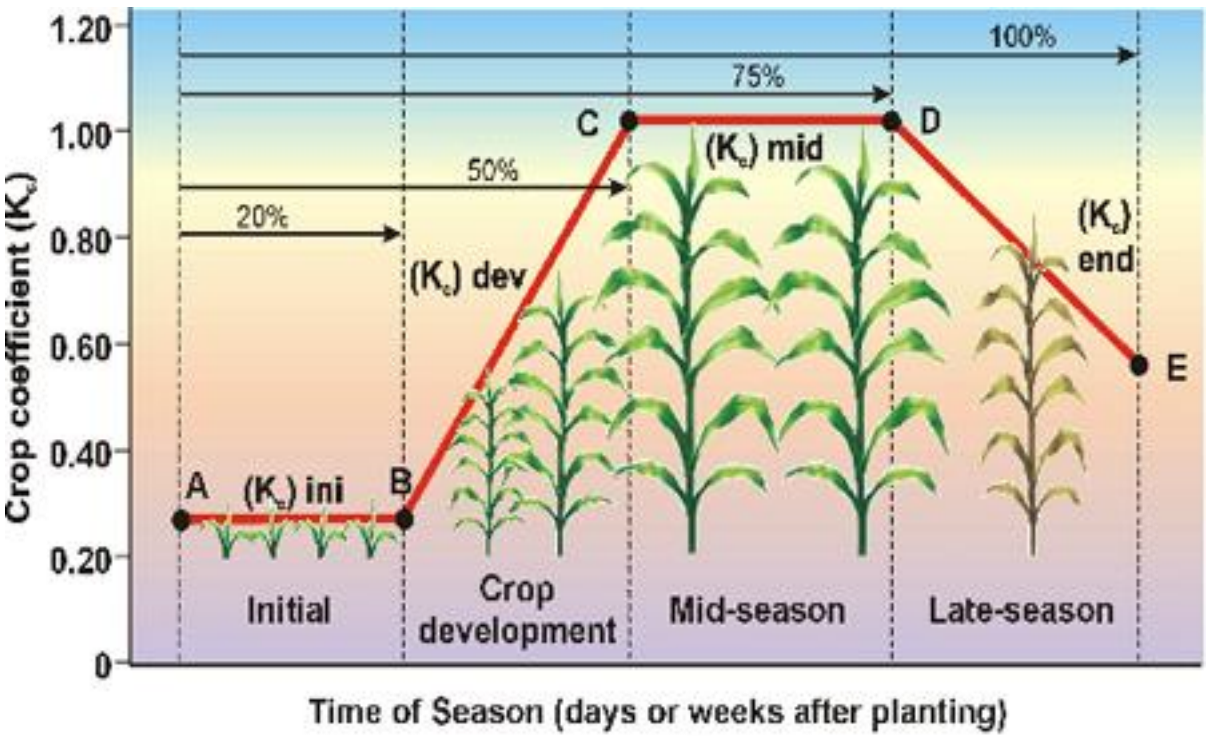
5.2. Crop Evapotranspiration

43. The most practiced way of estimating the crop ET rate (or crop water use rate) for a specific crop requires first calculating reference ETo and then applying the crop coefficients (Kc) to estimate actual crop ET (ETc) as

$$ETc = ETo\ (\text{Reference}) \times Kc$$

44. Kc is crop factor ETo is reference evapotranspiration calculated from software and Weather stations.

Figure 3 shows the Kc over complete growing period of crop



5.3. Previous Study Results

45. Punjab Irrigation Department, WAPDA and PMD collected the required climatic data manually and then meteorological variables were translated to the format required by the FAO recommended tools i-e CLIMWAT – 8 and CROPWAT – 8 for calculating evapotranspiration (ETo). Only two neighboring MET stations, Faisalabad and Multan, were utilized to extract data.

5.3.1. Faisalabad MET Station

Table 5 Climatic Normal of MET Station Faisalabad Pakistan Period 1981-2010

Latitude31°26' N Longitude 73°06´ E Elevation 183 M

Months	Normal Minimum Temp °C	Normal Maximum Temp °C	Normal Humidity %	Normal Wind Run Km /Day	Normal Sunshine Hours /day	Normal precipitation (millimeters)
January	4.7	19.0	52	62	6.2	11.1
February	7.5	22.1	44	124	7.0	19.1
March	12.9	27.1	40	133	7.8	23.8
April	18.3	34.1	29	156	8.6	23.7
May	23.7	39.1	26	169	9.6	14.9
June	26.7	40.2	32	196	8.9	43.8

July	27.2	37.3	50	204	8.0	100.8
August	26.7	36.4	55	196	8.1	87.0
September	24.0	35.6	47	151	8.9	42.5
October	17.4	32.8	39	71	8.7	4.7
November	11.0	27.3	45	36	7.8	2.0
December	5.8	21.7	50	36	6.6	7.1
Annual	17.16	31.06	42	128	8.01	381
Source: Pakistan Meteorological Department Regional Office Lahore. Climatic Data Station Faisalabad 1981-2010						

5.3.2. Multan MET Station

Table 6 Climatic Normal of Met Station Multan Pakistan Period 1981-2010

Latitude30°12' N Longitude 71°26´ E Elevation 122 M

Months	Normal Minimum Temp °C	Normal Maximum Temp °C	Normal Humidity %	Normal Wind Run Km /Day	Normal Sunshine Hours /Day	Normal precipitation (millimeters)
January	5.4	20.5	46	62	6.4	7.6
February	8.4	23.5	40	138	7.1	15.5
March	14.1	28.8	37	164	7.9	18.4
April	19.9	35.9	26	164	8.8	14.2
May	25.3	41.0	23	178	9.3	11.9
June	28.7	42.1	29	222	8.7	13.1
July	28.9	39.1	46	231	8.2	49.6
August	28.0	37.5	52	240	8.7	41.8
September	25.1	36.6	47	178	8.9	24.6
October	18.6	34.1	39	76	8.4	5.6
November	11.8	28.6	47	22	7.8	1.2
December	6.7	22.9	51	31	6.7	5.7
Annual	18.4	32.6	40	142	8.1	209
Source: Pakistan Meteorological Department Regional Office Lahore. Climatic Data Station Multan 1981-2010						

5.3.3. Determination of Evapotranspiration (ETo)

46. According to the recommendation of FAO, the Modified Penman-Monteith method is preferred to other methods because it yields better results. Therefore, Penman-Monteith method was used to compute reference crop evapotranspiration (ETo) through the program FAO CROPWAT 8. The climatic data for nearest MET Stations were obtained from the Directorate of Pakistan Meteorological Department, Lahore and converted into the required format for feeding into the CROPWAT – 8 program. The evapotranspiration and effective precipitation of both stations were separately computed and averaged to represent the ETo in the command area. The computed monthly values of Evapotranspiration and Effective Precipitation values are given in Table 9 below:

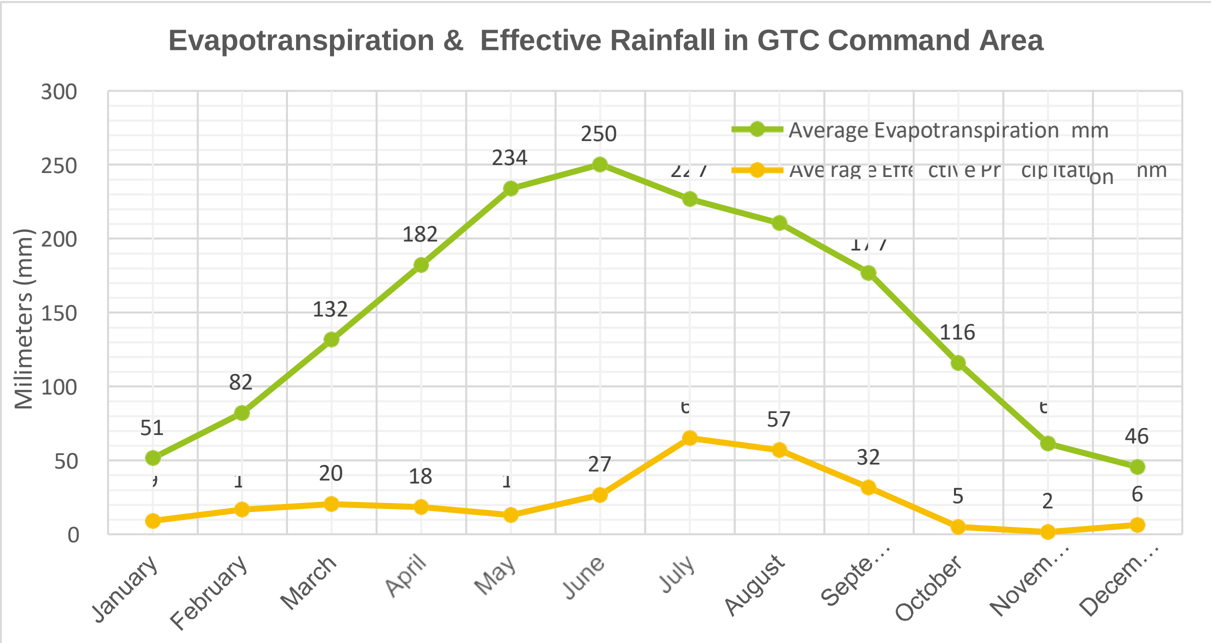
Table 7 Evapotranspiration and Effective Precipitation in the command area

Months	ETo monthly mm	Effective Precipitation mm
January	51	9
February	82	17
March	132	20
April	182	18
May	234	13
June	250	27
July	227	65
August	210	57
September	177	32
October	116	5
November	61	2
December	46	6
Annual	**1769**	**271**
Source: Computed with FAO CROPWAT 8 using Climatic Normals of PMD Stations Faisalabad and Multan ETO and EP Average of the Two Met Stations		

47. It should be noted that June has the highest evapotranspiration of 250 mm, followed by May and July with ETos of 234 and 227 mm, respectively. While June's effective rainfall is only 27 mm, May's is 13 mm, and July's is 65 mm. December had the lowest ETo of 46 mm, followed by January with a value of 51 mm. The month of July has the most effective rainfall with 65 mm, followed by August with 57 mm. No month has effective rainfall that matches the ETo. Annual evapotranspiration is 6.5 times effective precipitation, indicating a harsh desert climate that will make agriculture development difficult in the command area. Irrigation water is required for profitable farming. Below is a graphical representation of evapotranspiration against effective rainfall for easy understanding.

48. The graph below shows that effective rainfall is significantly less than evapotranspiration, needing controlled irrigation supplies for viable agriculture.

Figure 3 Trend of Evapotranspiration and Rainfall in Project Area



5.3.4. Present Study Results

49. The present study includes data of three nearby MET stations i-e Dera Ismail Khan, Sargodha and Faisalabad which was extracted from CLIMWAT – 8. These three stations were chosen by entering the latitude and longitude of Adhikot and CLIMWAT – 8 gave the neighboring three stations whose data was then imported to CROPWAT – 8 in a supported format. The data was processed and mapped in CROPWAT – 8 and obtained the ETo and effective precipitation of the general area of the greater Thal canal.

Figure 4 shows three MET Station from CLIMWAT – 8

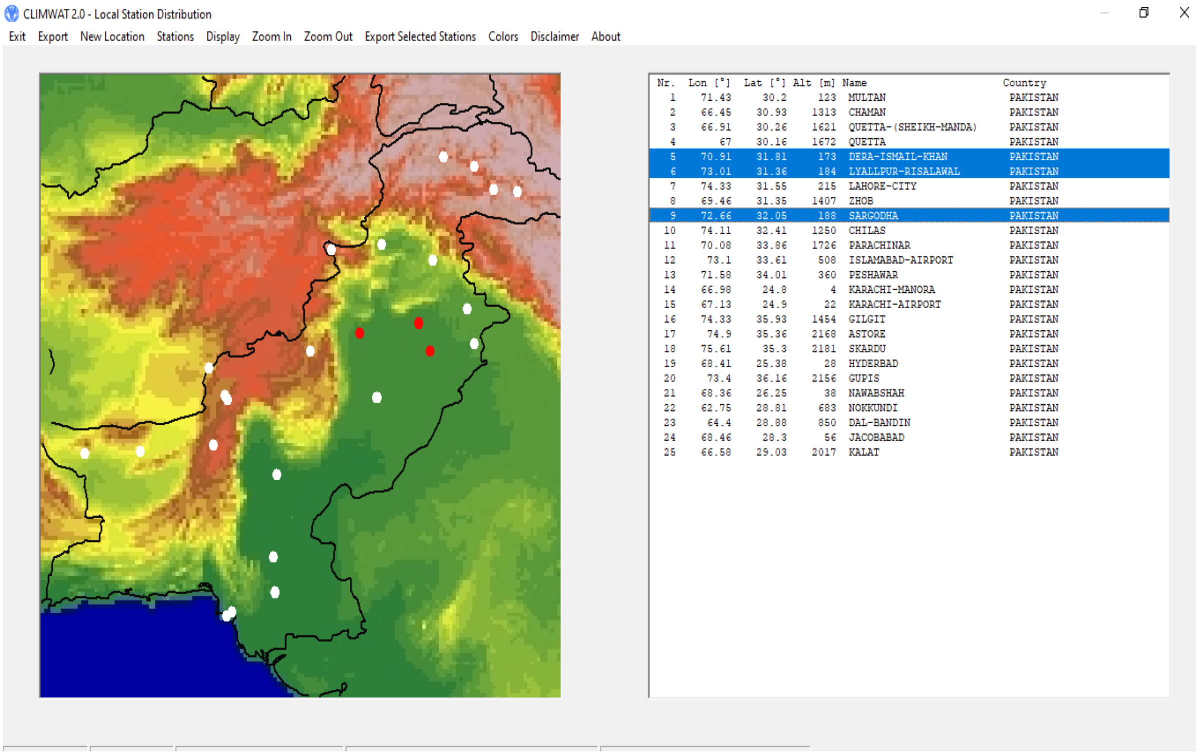
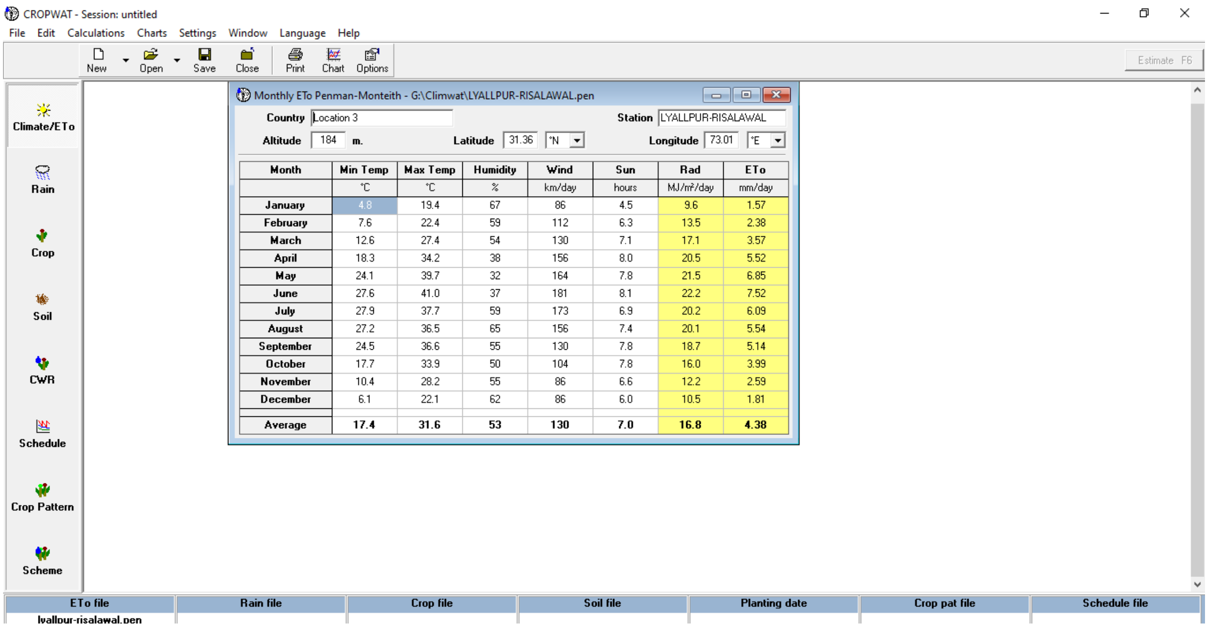


Figure 5 shows the climatic data extracted from CROPWAT – 8



5.3.5. Lyallpur/ Faisalabad MET Station

Table 8 Latitude: 31.4504° N Longitude: 73.1350° E Elevation: 182 M

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	4.8	19.4	67	86	4.5	9.6	1.57
February	7.6	22.4	59	112	6.3	13.5	2.38
March	12.6	27.4	54	130	7.1	17.1	3.57
April	18.3	34.2	38	156	8	20.5	5.52
May	24.1	39.7	32	164	7.8	21.5	6.85
June	27.6	41	37	181	8.1	22.2	7.52
July	27.9	37.7	59	173	6.9	20.2	6.09
August	27.2	36.5	65	156	7.4	20.1	5.54
September	24.5	36.6	55	130	7.8	18.7	5.14
October	17.7	33.9	50	104	7.8	16	3.99
November	10.4	28.2	55	86	6.6	12.2	2.59
December	6.1	22.1	62	86	6	10.5	1.81
Average	**17.4**	**31.6**	**53**	**130**	**7**	**16.8**	**4.38**

5.3.6. Sargodha MET Station

Table 9 Latitude: 32.0740° N Longitude: 72.6861° E Elevation: 186 M

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	4.7	18.9	69	138	6	10.9	1.79
February	6.4	22.8	65	173	6.2	13.2	2.61
March	12.5	26.9	62	233	7	16.8	3.95
April	17.6	33.2	50	285	8	20.5	6.31
May	21.9	37.5	38	311	8.8	23	8.42
June	26.7	41.5	37	294	8	22.1	9.05
July	27.6	37.7	61	337	7.5	21.2	7.34
August	26.3	36	68	294	8.1	21	6.26
September	24.1	36.1	61	207	8.1	19	5.64
October	17.3	33.4	56	164	8.1	16.2	4.47
November	10.1	25.4	59	121	7.9	13.3	2.69
December	5.4	21.2	64	104	7	11.2	1.82
Average	**16.7**	**30.9**	**57**	**222**	**7.6**	**17.4**	**5.03**

5.3.7. Dera Ismail Khan MET Station

Table 10 Latitude: 31.8625° N Longitude: 70.9018° E Elevation: 178 M

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.1	21.1	73	95	7.1	12.1	1.71
February	8.3	23.3	66	130	8.8	16.2	2.59
March	14.4	30	52	156	9.3	19.8	4.32
April	20	36.7	44	173	10.9	24.6	6.39
May	25.5	41.7	43	207	12.2	27.9	8.37
June	28.9	42.2	45	337	12.1	28.1	10.23
July	28.9	40	63	311	10	24.8	8
August	28.3	38.3	66	294	9.2	22.5	7
September	25	38.3	58	225	9	20.3	6.38
October	18.3	35.5	53	130	8.9	17.2	4.49
November	11.7	29.4	59	69	7.7	13.1	2.51
December	7.2	22.8	64	86	6.7	11	1.82
Average	**18.6**	**33.3**	**57**	**184**	**9.3**	**19.8**	**5.32**

5.3.8. Adhikot

Table 11 Latitude: 32.1055° N Longitude: 71.8082° E Elevation: 192.9 M

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.1	21.1	73	95	7.1	12	1.69
February	8.3	23.3	66	130	8.8	16.1	2.57
March	14.4	30	52	156	9.3	19.8	4.3
April	20	36.7	44	173	10.9	24.6	6.38
May	25.5	41.7	43	207	12.2	27.9	8.37
June	28.9	42.2	45	337	12.1	28.1	10.23
July	28.9	40	63	311	10	24.8	8
August	28.3	38.3	66	294	9.2	22.5	6.99
September	25	38.3	58	225	9	20.2	6.37
October	18.3	35.5	53	130	8.9	17.1	4.47
November	11.7	29.4	59	69	7.7	13	2.48
December	7.2	22.8	64	86	6.7	10.9	1.8
Average	**18.6**	**33.3**	**57**	**184**	**9.3**	**19.8**	**5.31**

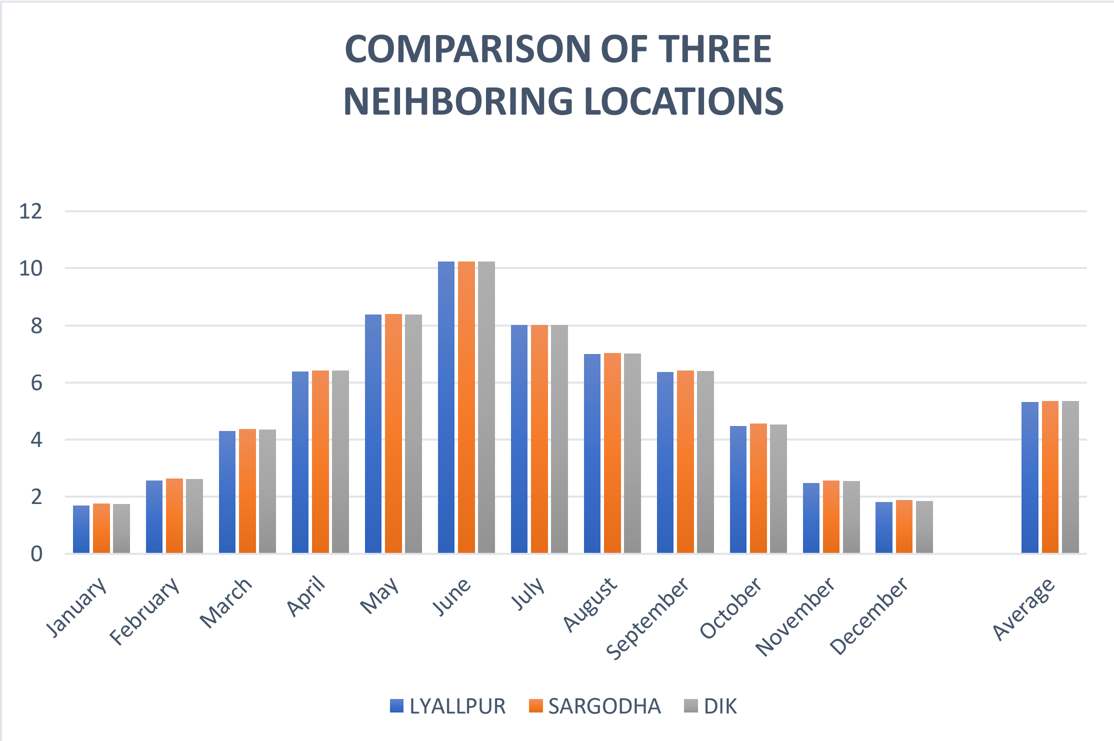
5.3.9. Comparison of ETo's of all Neighboring MET Stations

Table 12

Month	LYALLPUR	SARGODHA	DIK
	ETo mm/day		
January	1.57	1.79	1.71
February	2.38	2.61	2.59
March	3.57	3.95	4.32
April	5.52	6.31	6.39
May	6.85	8.42	8.37
June	7.52	9.05	10.23
July	6.09	7.34	8
August	5.54	6.26	7
September	5.14	5.64	6.38

October	3.99	4.47	4.49
November	2.59	2.69	2.51
December	1.81	1.82	1.82
Average	4.38	5.03	5.32

Figure 6



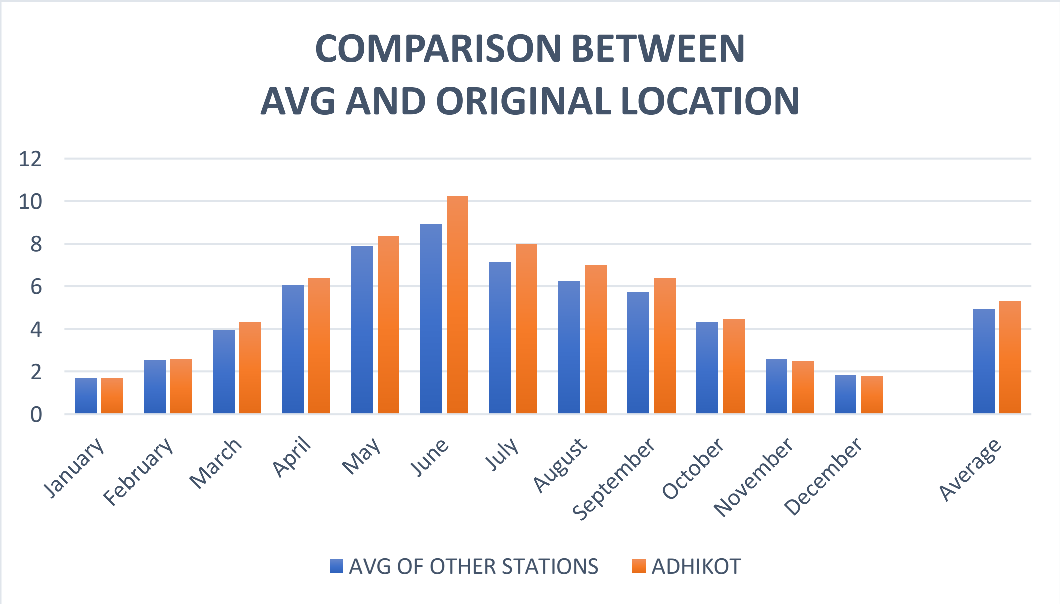
50. From above chart, it evident that there is negligible difference between the values of ETo of Lyallpur, Sargodha and Dera Ismail Khan. We will take average of the values of these stations and compare it with Adhikot, which was inserted manually in CLIMWAT – 8 to obtain its ETo.

5.3.10. Comparison of Adhikot Station and Neighboring 3 Stations

Table 13

Month	Average of 3 Neighboring stations	ADHIKOT
	ETo	ETo
	monthly	monthly
January	50.7	50.7
February	75.8	77.1
March	118.4	129
April	182.2	191.4
May	236.4	251.1
June	268	306.9
July	214.3	240
August	188	209.7
September	171.6	191.1
October	129.5	134.1
November	77.9	74.4
December	54.5	54
Average	**147.3**	**159.3**

Figure 7



51. From above table/ chart of comparison between three neighboring stations and the point from the canal is off taking i-e Adhikot is almost similar. It is evident that the neighboring stations can be used for calculating evapotranspiration (ETo) because the conditions are almost similar.

5.3.11. Precipitation (Effective Rainfall Data)

Table 14

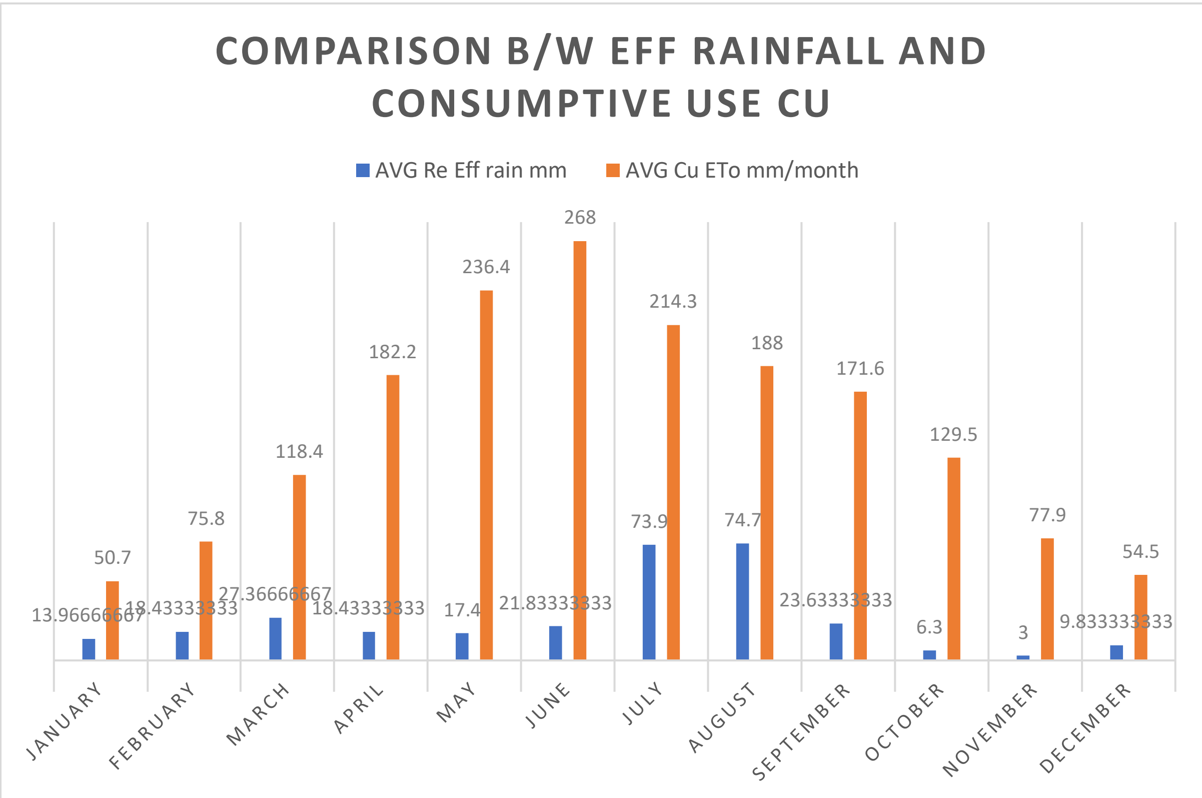
Months	LYALLPUR		DIK		SARGODHA	
	Rain	Eff Rain	Rain	Eff Rain	Rain	Eff Rain
	mm/ month					
January	16	15.6	10	9.8	17	16.5
February	18	17.5	18	17.5	21	20.3
March	23	22.2	34	32.2	29	27.7
April	14	13.7	20	19.4	23	22.2
May	9	8.9	19	18.4	26	24.9
June	29	27.7	16	15.6	23	22.2
July	97	81.9	57	51.8	106	88
August	98	82.6	52	47.7	115	93.8
September	29	27.7	17	16.5	28	26.7
October	5	5	5	5	9	8.9
November	2	2	2	2	5	5
December	8	7.9	9	8.9	13	12.7
Total	348	312.5	259	244.7	415	368.9

5.3.12. Effective Precipitation and Consumptive Use of GTC Area

Table 15

MONTH	Average Re	Average Cu	Average Cu	CIR
	Eff rain	ETo	ETo	ETo
	mm	mm/day	Mm/Month	mm
January	13.96667	1.69	50.7	36.7333333
February	18.43333	2.526667	75.8	57.3666667
March	27.36667	3.946667	118.4	91.0333333
April	18.43333	6.073333	182.2	163.766667
May	17.4	7.88	236.4	219
June	21.83333	8.933333	268	246.166667
July	73.9	7.143333	214.3	140.4
August	74.7	6.266667	188	113.3
September	23.63333	5.72	171.6	147.966667
October	6.3	4.316667	129.5	123.2
November	3	2.596667	77.9	74.9
December	9.833333	1.816667	54.5	44.6666667
Total	308.7	58.91	1767.3	

Figure 8



52. The above chart shows the difference between effective rainfall and net consumptive use. It also validates additional water is required for the GTC command areas for irrigation.

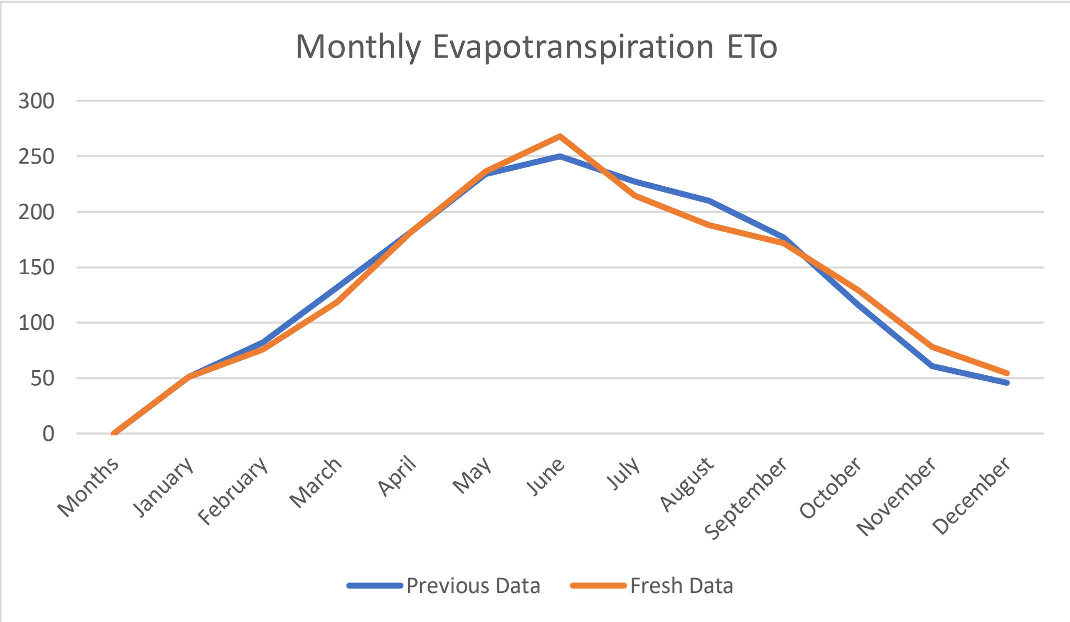
5.4. Validation of Data of Previous and Present Data

5.4.1. ETo Comparison

Table 16

Months	ETo monthly (Previous Data)	Average ETo Monthly (Fresh calculated Data)
	mm	mm
January	51	50.7
February	82	75.8
March	132	118.4
April	182	182.2
May	234	236.4
June	250	268
July	227	214.3
August	210	188
September	177	171.6
October	116	129.5
November	61	77.9
December	46	54.5
Annual	1769	1767.3

Figure 9



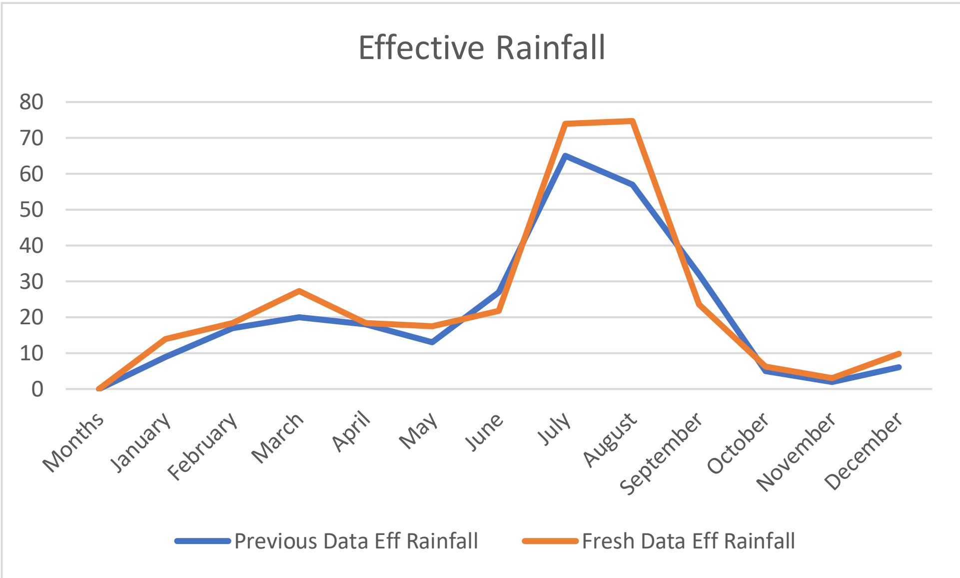
53. The above table shows that the ETo calculated by the Irrigation Department of Punjab is very close to the data calculated in this project. However, there were three MET stations used in this calculation and previously there were only two MET stations i-e Lyallpur and Multan.

5.4.2. Effective Precipitation Comparison

Table 17

Months	Effective Precipitation	
	Mm (Previous)	mm (Latest)
January	9	13.96667
February	17	18.43333
March	20	27.36667
April	18	18.43333
May	13	17.4
June	27	21.83333
July	65	73.9
August	57	74.7
September	32	23.63333
October	5	6.3
November	2	3
December	6	9.833333
Annual	**271**	**308.7**

Figure 10



54. From the above table, we can see there is a slight difference in an annual effective precipitation. This difference is because of climate change.

5.5. Calculation Of Discharge

5.5.1. Calculation of ETc

Table 18

Month	ETo mm	CIR (Cu) mm	Wheat Kc	Wheat ETc mm	Millet Kc	Millet ETc mm	Sugarcane Kc	Sugarcane ETc mm
November	77.9	74.9	0.14	10.486	-	-	0.38	28.462
December	54.5	44.7	0.4	17.88	-	-	0.36	16.092
January	50.7	36.7	0.53	19.451	-	-	0.68	24.956
February	75.8	57.34	0.78	44.7252	-	-	0.44	25.2296
March	118.4	91.1	0.97	88.367	-	-	0.31	28.241
April	182.2	163.8	0.56	91.728	-	-	0.34	55.692
May	236.4	219	-	-	-	-	0.51	111.69
June	268	246.12	-	-	-	-	0.91	223.9692
July	214.3	140.4	-	-	0.64	89.856	0.13	18.252
August	188	113.3	-	-	1.1	124.63	0.117	13.2561
September	171.6	147.97	-	-	1.23	182.0031	0.115	17.01655
October	129.5	123.2	-	-	1.12	137.984	0.102	12.5664

Average			**0.563333**		**1.0225**		**0.366167**	
Total		**1458.53**		**272.6372**		**534.4731**		**575.4229**

5.5.2. Delta

55. It is the total depth of the water required by a crop during the entire period the crop is in the field and is denoted by the symbol Δ.

5.5.3. Duty

56. The term duty means the area of land that can be irrigated with unit volume of irrigation water. Duty represents the irrigating capacity of a unit. It is the relation the between the area of a crop irrigated and the quantity of irrigation water required during the entire period of the growth of that crop.

5.5.4. Base Period

57. Base Period for a crop refers to the whole period of cultivation from the time when irrigation water is first issued for preparation of the ground for planting the crop, to its last watering before harvesting.

5.5.5. Effective Crop Area

58. To calculate effective crop area, we multiply CCA with Crop Intensity of that specific crop.

5.5.6. Calculation Of Discharge

59. To calculate the requirement of discharge of specific crop, following relation is used Q=Area/Duty (Cumec)

Table 19

Ser	Crop	Crop Intensity	Delta (∆)		Area (A)	Crop Area	Crop Period (B)	Duty (D)	Discharge (Q)
		%	Etc (mm)	Etc(m)	Ha	Ha	Days	Ha/Cumec	Cumec
								D=(8.64*B)/∆	Q=Area/Duty
1	**Wheat**	19.7	272.6372	0.272637	143983	28364.651	180	5704.283935	**4.972517379**
2	**Millet**	13.9	534.4731	0.534473	143983	20013.637	120	1939.85441	**10.31708199**
3	**Sugarcane**	3.3	575.4229	0.575423	143983	4751.439	180	2702.708104	**1.758028917**

5.6. Cropping Calendar or Growing Season of Crops

60. Crop evapotranspiration ETc. varies with the type of crops and climatic conditions i.e., rainfall, wind speed, humidity, temperature, and sunshine etc. To estimate crop water requirements, type of crop, time of sowing and harvesting and the length of the growing period is also required. The primary data about cropping calendar, time of sowing, growing and harvesting of different crops have been collected from the farmers through agronomic survey of the project area and adjusted with the cropping calendar published by the Department of Agriculture Extension. The information has been applied as per procedure in FAO Irrigation and Drainage Paper 56 "Crop evapotranspiration - Guidelines for computing crop water requirements" to evolve crop coefficients (Kc) at different stages of crop growth by 10-day periods of the calendar months.

5.7. Effective Precipitation

61. The effective rainfall is subtracted from the consumptive use of crops to arrive at net consumptive use to be provided through irrigation. Effective rainfall is that part of precipitation which directly meets the crops water requirements. Effective precipitation has been computed by U.S. Bureau of Reclamation Method using FAO software Cropwat 8. The monthly effective precipitation has been split into 3 10-daily periods and placed in the

computation model to determine the net consumptive use by 10 daily periods of calendar months.

5.8. Net Consumptive Use

62. The net consumptive use is the depths of irrigation water, exclusive of effective rainfall, carry over soil moisture etc. required consumptively for crop production. It is the quantity of irrigation water required to bring the soil moisture level in the effective root zone to the field capacity. The net consumptive use in a Project irrigation scheme is the total consumptive use (mm) less effective rainfall (mm). The net consumptive water use has been computed by subtraction of effective precipitation from the consumptive use of each crop.

5.9. Project Irrigation Efficiency

63. Not all the water diverted at the source reaches the crop root zone for consumptive use by the crops. Several types of water losses occur on the way from canal head to crop root zone, lowering the efficiency of the irrigation system. The main losses are conveyance losses in the canal, distributary, watercourse and field application losses. These losses have been estimated in consultation with the Project Irrigation Engineer and On Farm Water Management Engineer using international standard procedures and assumptions. It has been assumed that in the lined canal in the Project command area, the conveyance efficiency would be 95%. The conveyance efficiency of lined watercourse is assumed as 80%. The field application efficiency is assumed as 65%. Thus, the irrigation efficiency computes to 46.93% for the Project area.

64. In case of groundwater irrigation, the tube well is within the farm boundary and not far away. So, watercourse conveyance losses are approximately 10% depending on the distance and type of farm watercourse. Field application is the same as the in canal system as the soils are the same. Thus, the groundwater efficiency has been worked as 0.65x 0.925= 60.13%.

5.10. Gross Project Irrigation Requirements

65. The gross irrigation water required to be diverted at source (canal head) to meet the crop water requirements have been worked out considering efficiency of field application, conveyance efficiency of watercourse, distributary and main canal. This equation gives the diversion requirements at the source of irrigation water.

66. Gross Irrigation Water Requirements = Net CWR ÷ Irrigation Efficiency of the System at Canal Head (source).

5.11. Gross Irrigation Requirements for GTC Command Areas

67. Gross irrigation requirements of the GTC Phase for the designed cropping pattern and intensities have been worked out by 10-daily periods and matched with the water availability. In the beginning of the canal water supply term (April) and later (September)

the availability is short of the crop water requirements. Thus, conjunctive use of groundwater has been planned to meet water shortages. The sowing time of melons (February end) is before the start of canal supplies, so groundwater was applied till the beginning of canal supplies in April. Cotton need irrigations in October while Zaid Kharif Onion in October and November to mature the crops. Alfalfa and orchards are perennials and have been planned to be irrigated with groundwater abstraction before and after the canal supply term (April- September).

Rabi season crops are mainly rain fed, however some crops like wheat, alfalfa and orchards are irrigated with groundwater abstraction. The existing cropping pattern and intensities in Rabi are expected to continue as such with or without Project. Groundwater abstraction during Rabi has been estimated through computation of crop water and irrigation requirements to understand its impact on aquifer balance.

68. Kharif season existing crops in Chaubara and Phase -III command area, where there are no canal water supplies, are obviously irrigated with groundwater abstraction. Rainfed crops in Kharif are less than 1%. This level of cropping intensities is going to continue without Project interventions.

69. It may be briefed that crop water and irrigation requirements for with Project Scenario from canal and groundwater has been estimated. The existing or without Project water use especially groundwater abstraction has also been quantified to see its impact of aquifer equilibrium.

6. Recommendations

70. By using modern tools like CLIMWAT-8 and CROPWAT-8, we validated the ETo And Re (Effective Precipitation) against the values calculated by manual/ field methods. There was very little difference which can be neglected due to changes in intensity of rain and several other climatic factors. So it is recommended that this method should be used to calculate ETo and Re of any particular area for its importance in calculating several irrigation parameters.

71. Due to lack of awareness farmers tend to over or sometimes under irrigate the field which results in lower yields of crops. Therefore, it is recommended that the farmers should be made aware of the exact time to irrigate their crops in unit acres as the smallest unit. This should be done for all types of crops and be displayed at every outlet. The current system allows them take their share of water as per Warrabandi. The time table can be achieved by following step:-

   a. Calculated ETo can also be used to calculate frequency of watering (fw) in days. For that we just must know dw i-e depth of water to be given during each watering.

$$d_w = \frac{\square_d}{\square_w} d\,[F_c - m_o]$$

Where,
Fc is Field capacity
Mo is lower limit of readily available moisture content
d is root zone depth

After dw is calculated, we can calculate frequency of watering (fw) by

$$f_w = \frac{d_w}{C_u}\ days$$

We can use these calculations to calculate further the time required to irrigate a specific area/ field by

$$t = \frac{A * dw}{Q}$$

72. The discharge can also be calculated by using the CROPWAT – 8 by calibrating it to the conditions accurately. It gives the crop factor of the given area as per FAO recommendations and then further calculate the crop water requirements of that crop for complete cropping period. It is recommended that CROPWAT should be used to calculate only after proper calibration of the software.

73. Solar panels can help prevent water loss through evaporation by shading canals. It is a modern technique to cater for the loss of water through evapotranspiration and for generation of electricity as well. This technique has already been in practice in USA, Japan and India. It also reduces habitat loss by placing panels in already-dedicated man-made spaces rather than clearing new land. The 60% conveyance loss can be reduced considerably. It's a very convenient option because land acquisition would not pose a problem moreover the walls of canal will be used to install the panels.

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