ESTIMATION OF POTENTIAL AND ACTUAL CROP EVAPOTRANSPIRATION USING WEAP MODEL

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ABSTRACT: *Ever increasing needs of food and fiber, the irrigated agriculture is under immense pressure. Due to increasing demands the canals must run on the demand basis keeping in view the water availability, type of soil in the area, meteorological parameters and crops stages of each canal in order to fulfill the crops requirements to achieve the maximum yield. During this study, Hakra 4R distributary canal was selected and potential and actual crop evapotranspiration of the major crops sown in the canal command area using WEAP model.*

INTRODUCTION

In canal irrigation systems in Indo-Pak, water supplies reach the fields through a network of main canals, branch canals (secondary canals) and distributaries (tertiary canals). The distributary is the basic unit of irrigation management in large canal systems, as it is the last point of control in main irrigation systems operation [1].

Agriculture plays pivotal role in national economy and irrigated agriculture contributes more than 80 percent to national agricultural production. Successful crop cultivation is only possible with irrigation in Pakistan. Owing to irrigation requirements, the world’s largest irrigation system was laid out in Indus Basin, almost a century ago. Irrigation Department has been custodian of the irrigation system since its inception. The department operated and managed the system in a successful way in the past. However, with the passage of time, the department could not continue the pace required to improve its capacity for efficient and effective management of the system. Consequently, the system operation and management rely on the century old rules and practices, which are incapable to run the system effectively and efficiently under present conditions. The agro-based economy of Pakistan mainly depends on the Indus Basin irrigation system. It accounts for about 21% of Pakistan’s gross domestic product (GDP) and employs about 44% of its labour force. Pakistan measures about 80 million hectares (ha) of which 22 million ha are cultivated. Of this cultivated area 19.6 million ha are irrigated (Agricultural Statistics of Pakistan 2006–2007) [2]. Major crops are wheat, rice, cotton, maize and sugarcane, which together occupy about 63% of the total cropped area [3]. Between 1981 and 2007, wheat and rice production also increased proportionally to the population, which grew from 85 million to 160 million in the same period (Agricultural Statistics of Pakistan, 2006–2007).

Punjab irrigation system network is a century’s old which transfer river water through Headworks / Barrages to the farmer fields for the growing of crops. Among the four Provinces, Punjab Irrigation system consists of 13 barrages, 26 main canals, 12 link canals covering the area about 8.56 million hectares. This irrigation network is serving 21 million acres (8.4 million hectors) cultivable command area through 58,000 outlets having cropping intensities generally exceeding 125%.

Punjab Irrigation System is vital to Pakistan’s Economy Covers 60% of IBIS, Contributes 66% to National Agricultural Gross Domestic Product (GDP) and Produces following percentages of crops:

- 80% of wheat
- 75% of Cotton
- 64% of Sugarcane
- 58% of Rice

Operation of the System involves planning of the available water resources and transferring the cheap and good quality water to the irrigation fields keeping in view the crop water requirement corresponding to the various stages or the crop growth.

Current status of decision making in irrigation water management is largely based on experience rather than scientific tools and techniques. Such decisions are usually incapable to meet the needs of efficient irrigation system operation and management. This situation demands a shift to new paradigm of decision making in irrigation water management based on a comprehensive decision support system (DSS) [4].

STUDY AREA

The Fordwah/Eastern Sadiqia Irrigation System is situated on the left bank of the Sutlej River and is confined by the Indian border in the east and by the Cholistan Desert in the Southeast [5]. The Distributary No. 4-R also known as Haroonabad canal in the Hakra Branch Canal of the Fordwah Eastern Sadiqia irrigation system [6] is one of the largest distributaries in the Punjab Province. It has a total discharge of 6.39 cubic meters per second (cumecs), or 226 cusecs, and a total of 123 irrigation outlets (watercourses) serving a command area of nearly 17,593 hectares. The main channel of the Hakra 4-R Distributary system has two minors’ 1-RA Labsingh and 1-R Badruwala off-take from the main channel at RDs 23 + 200 RD and 72 + 100 RD respectively. The 1-RA Labsingh Minor consists of 15 irrigation outlets, and has a design discharge of 0.6 cumecs (22 cusecs), covering a canal command area of 2,460 hectares. The 1-R Badruwala Minor is the largest section of the Hakra 4-R Distributary system. The minor is unlined, is about 15 kms (50,620 ft) long, and has 33 irrigation outlets and a design discharge of 1.2 cumecs (43 cusecs), to serve a canal command area of 8,815 hectares.

In the Hakra 4R canal command area Cotton- Wheat cropping pattern adopted. For the kharif cotton crop and rabi season, wheat, although less profitable, is the most popular crop sown in the area.

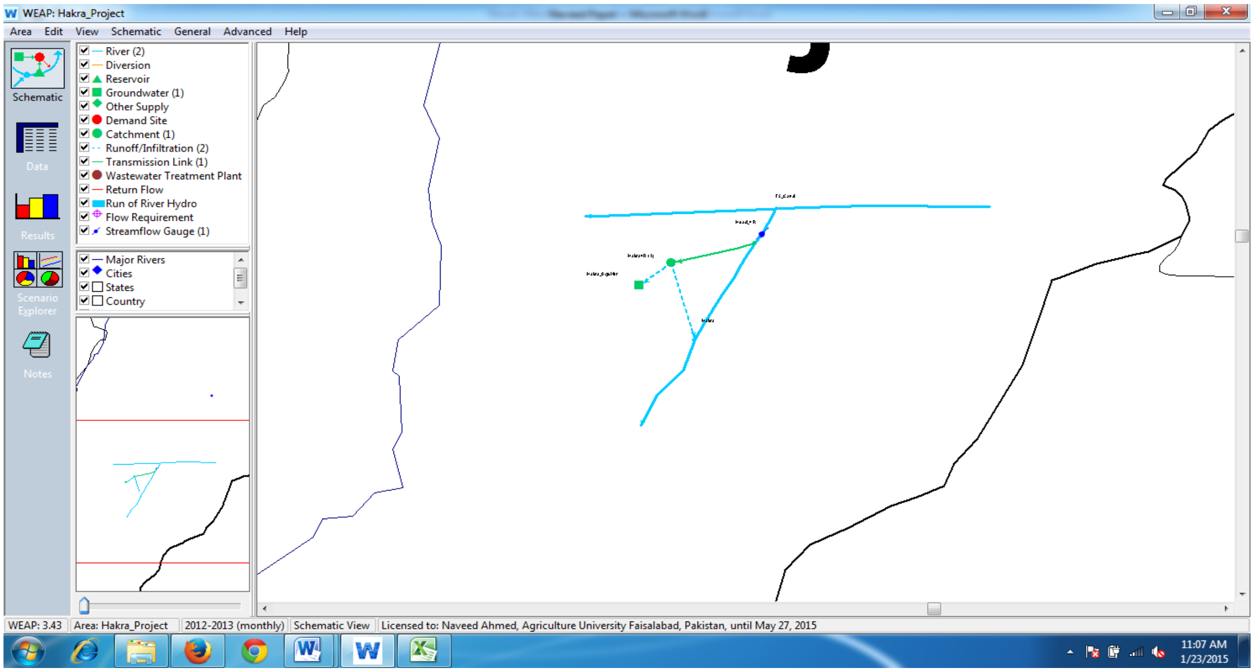

Figure 1: WEAP Model Schematic View Layout for Hakra 4R

The canal do not run throughout the year, there is a canal closure period in the irrigation canals usually in the month of December and January. Hakra 4R Distributary canal closure period was observed which is from December 20, to January 31, of each year.

METHODS

Decision Support System

The advent of computers, technology and availability of simulation models make it possible to take knowledge based decisions on complicated system parameters. The challenge lies to translate the variety of information and simulations into meaningful information for policy makers and system managers. The Decision Support System would integrate diversity into simplified interactive modules. Such a system would enable the users to test a variety of available options through model simulations and get the optimal solutions for an efficient system operation and management.

The DSS produces "real time" solutions to the problems taking into account the water availability, demand, climate, hydrology and physical conditions of the system. On an overall basis, the DSS is be a software package consisting of interactive forecasting, hydrological, optimization etc. and provides integrated solutions to the long term and day to day irrigation system operation and management.

DSS is a computer-based set of tools having interactive, graphical and modeling characteristics to address specific problems and assist users in their study and search for a solution to their problems.

The DSS link up the irrigation demands for the area irrigated by that canal lying under its command area. For the real time estimation of water demands in each canal under study, the model will be used with current information of weather and canal flows in each season and type of the soil. As the distributary is the main unit of operation of canal water to farmers, so we have to integrates well with the actual process of decision-making by the operators of canal irrigation systems [1].

WATER EVALUATION AND PLANNING (WEAP) MODEL AS "DSS" TOOL [7]

WEAP ("Water Evaluation And Planning" system) is a user friendly software tool that takes an integrated approach to water resources planning. Freshwater management challenges are increasingly common. Allocation of limited water resources between agricultural, municipal and environmental uses now requires the full integration of supply, demand, water quality and ecological considerations. The Water Evaluation and Planning system, or WEAP, aims to incorporate these issues into a practical yet robust tool for integrated water resources planning.

WEAP model is fully integrated water resources system analysis software which uses the integrated approach for water resources planning. WAP is based on linear programming and is a simulation model that integrates water demands from all sectors of water supply such as rivers, reservoirs, canals and groundwater [8, 9]. It use the catchment rainfall runoff module which is based on the hydrological processes including infiltration, effective precipitation, deep percolation, root zone moisture depletion and irrigation demand based on the crops sown in the area and type of the soils. WEAP layout used in this study is shown in figure 1.

The actual monthly flows data from January 2012 to December 2013, wind speed (m/sec) Maximum, Minimum Temperature (^{o}C), Average Humidity, Minimum, Maximum and effective precipitation, was collected from the Pakistan Meteorological Department (PMD) Lahore, on daily basis.

EVAPOTRANSPIRATION

The loss of water from the wet surface of the soil and from the plant leaves collectively is known as evapotranspiration (ET) [10].

Loss of water from the wet soil surfaces is known as evaporation. During this process the water from liquid phase is converted into water vapours this phenomena is called vaporization. Water vaporization took place from all the water bodies' surfaces which are open to atmosphere such as rivers, canals, reservoirs, lakes,

ponds and wet soil surfaces. As the water is evaporated from the water surface, the surrounding air picked up these water vapours and become heavier as compared to the air which has not received these vapours. The lighter air replaced this saturated air and picked up the water vapours from the water bodies, this process continues until the surrounding air of the water body become fully saturated. The evaporation process depends upon the wind speed, temperature variations, humidity, solar radiations and other meteorological parameters [10].

On the otherhand, the second process of evapotranspiration is the loss of water from the plant tissues to the atmosphere by the small openings present in the plant leaves known as stomata. This loss of water from plants is referred to transpiration. The evaporation

and transpiration collectively referred as Evapotranspiration [10].

MODELLING PROCESS USING WEAP

There are four different types of hydrological models used for estimation and simulation of runoff, evapotranspiration, irrigation demands and infiltration etc. in WEAP. These methods are listed below:

1. Rainfall Runoff Method (Simplified Coefficient Method),
2. Irrigation Demands Only (Simplified Coefficient Method),
3. Rainfall Runoff Method (Soil Moisture Method); and
4. MABIA (FAO 56, dual Kc, daily)

The first three methods were used in the previous versions of the WEAP model but in the latest WEAP version fourth one is an additional method used [12]. In this study, MABIA method was used keeping in view the scope of work and the advantage of this method.

What is MABIA Method?

Evaporation, transpiration, irrigation scheduling, irrigation water requirement, crops growth, and crop yield is simulated on the daily basis. Moreover, soil water capacity and reference evapotranspiration is also estimated by MABIA method [12].

Dual Kc approach is used in MABIA method as it is discussed in great detail in FAO, Irrigation and Drainage Paper No. 56. In this dual Kc approach, Kc is divided into two components (coefficients), one is called "basal crop coefficient K_{cb}" and the second is "evaporation component K_e (from wet soil surface). At the actual evapotranspiration conditions when the soil surface look dry but still there is water present which is available to the crops for the process of transpiration, represents the K_{cb} [12].

Method for the Estimation of Basal Crop co-efficient (K_{cb})

For the estimation of the basal crop coefficient (K_{cb}), empirical approach is used discussed in the below paragraphs.

The ratio of the crop evapotranspiration to reference evapotranspiration (ET_c / ETo) is called basal coefficient K_{cb}, when the soil surface seems to be dry but water is present from the root zones to the crops for transpiration [10]. Basal crop coefficient, for the crop under consideration during its season length at any stage of its growth may be estimated. The whole crop season length is divided into initial, middle, development and final stage. Basal crop coefficient is estimated by assuming that during initial and middle stage of crop growth "K_{cb}" is constant and its value is equal to the growth stage under discussion. During the remaining two stages, its value varies linearly from K_{cb} value at the end of the last (previous) stage (K_{cbprev}) and K_{cb} value at the start of the start of the next stage (K_{cbnext}) [10, 12]. Following expression is used for its calculations:

$$K_{cbi} = K_{cb\ prev} + \left[\frac{i-\sum L_{prev}}{L_{stage}}\right]\left(K_{cbnext} - K_{cbprev}\right) \quad (1)$$

Where;

i = Number of the day in the growing season,

Kcbi = Basal crop coefficient on the "i" day,

Lstage = Stage Length under consideration (days),

∑Lprev = Sum of lengths of all previous stages (days),

In the WEAP Model the values of Kcbi and Lstage come from the Crop Library.

Evaporation co-efficient component (K_e) of MABIA Method

When the soil top surface is wet the evaporation takes place from this top surface and reached upto its maximum rate. When the soil surface is dry, the values of K_e will be small and until become zero representing there is no water present in the soil near to the surface for evaporation. However, the dual crop co-efficient (Kc =Kcb +Ke), can never exceed the maximum value [10].

Cropping Schedule and Crop Library in WEAP

In the Hakra 4R distributary canal command the cropping pattern is cotton-wheat as discussed in the previous chapter. Typical planting months for the cotton are Mar/May and that of Wheat Nov/Dec. The Cotton Crop, planting start date is May 15 and end date is November 25 with the total cotton crop span of 195 days and for wheat crop the total crop length is 171 days, planting start date is November 26 and end date is May 14.

In the WEAP crop library based on the crops grown in the areas and their total length was divided into initial, development, middle and end days. On the basis of these divisions of crop stages the WEAP calculates the Basal Crop Co-efficient (K_{cb}) in each stage [12].

Soil properties in Hakra 4R and WEAP

Water holding capacity, field capacity and wilting point are the parameters which depends upon the type of the soil in the command area. The soil type in the Hakra 4R canal command is Silt-loam, and the soil layer thickness which subject to evaporation was 0.11 m. On the basis of this information maximum infiltration rate is 168 mm/day and soil water capacity 21.4 percent for silt-loam soil.

At the wilting point and field capacity, MABIA method required data of water holding capacity for land use of the catchments. The measurements of wilting point, water holding capacity, field capacity of the soil are time consuming and costly activities. However, in WEAP model pedotransfer functions are available for the estimation of these parameters of the soil [12].

Potential Crop evapotranspiration

Potential crop evapotranspiration is the ability of atmospheric parameters to remove water by evaporation and transpiration.

$$ET_c = (K_{cb} + K_e) * ET_{ref} \qquad (2)$$

Actual Crop evapotranspiration (ET_a)

When the crop evapotranspiration (ET_c) required for a crop is more than the amount of irrigation applied and precipitation, under this situation moisture contents in the root zone of the crops reduced upto lowest level and plant could not extract the amount of water in order to full fill the required ET_c. Eventually, soil water stress occurred and actual evapotranspiration (ET_a) value is less than the crop evapotranspiration (ET_c) [12] and estimated by:

$$ET_a = K_{act} * ET_{ref} \qquad (3)$$

Where;

$$K_{act} = K_s K_{cb} + K_e$$

Ks is the soil stress co-efficient and other parameters in the above equation are already described in previous section. Ks is estimated by the following equation in WEAP.

$$K_s \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW} \qquad (3)$$

Where;

K_s = Soil stress coefficient (dimensionless),

TAW = Total available Water in the root zone (mm),

D_r = Water depletion in the root zone (mm),

RAW = Readily available water (mm); and

p = Depletion factor

When the value of water depletion (Dr) in the root zone is less than or equal to the readily available water (RAW), the value of soil stress coefficient will be equal to one (Ks=1, when Dr≤ RAW). When the soil is at field capacity the water depletion value is zero (Dr=0). Soil water stress increases as the depletion in the root zone increases until it got maximum value when across the RAW. The values of depletion factor (p) varies crop to crop during its growth stages and range from 0.4 to 0.6 for shallow and deep root crops [10, 12].

RESULTS

POTENTIAL AND ACTUAL CROP EVAPOTRANSPIRATION

In the figure 2 and 3, the comparative graph for both Actual and Potential Crop Evapotranspiration (inches) is given using MABIA method of dual K_c approach for wheat-cotton cropping pattern for the year 2012 – 2013. The difference between potential and actual crop evapotranspiration is known as water need of the crops.

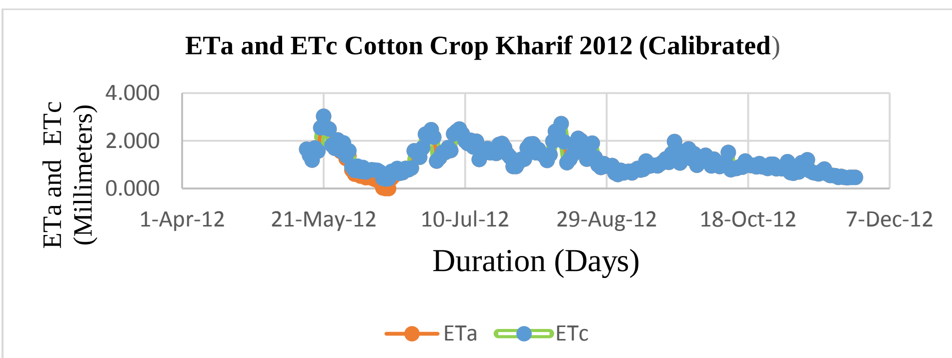

Figure 2: Potential and Actual ET (Millimeters) in Hakra 4R by WEAP

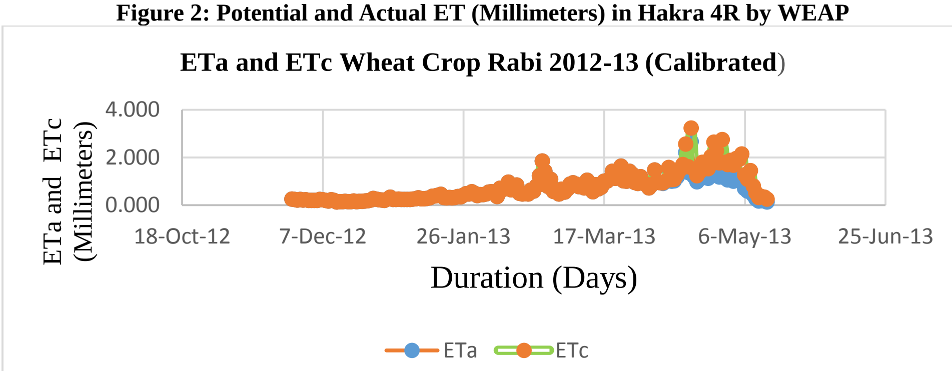

Figure 3: Potential and Actual ET (Millimeters) in Hakra 4R by WEAP

CONCLUSION AND RECOMMENDATION

Cotton crop season length in the Hakra 4R canal command area is 195 which starts from May 15 to Nov 25 in WEAP and for Wheat crop the season length is 171 days which starts from Nov 26 to May 14. Keeping in view the planting and harvesting dates of each crop, it is estimated that the difference between potential and actual crop evapotranspiration is high during the months of August and September 2012 for cotton crops and for Wheat crop during March and April Months.

In the month of December and January there is no flow actually in the canal but there is wheat crop sown in the command area and to fulfill the crop water requirement, firstly canal should run in these months which is not possible, secondly the only required amount of water should be pumped during these days of higher actual evapotranspiration.

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