Techno-Science Research Journal 3 (2015) 8-14

Content list available at ITC

Techno-Science Research Journal

Journal Homepage : www.itc.edu.kh

Techno-Science Research Journal

Application of CROPWAT model to estimate rice water requirement at field scale in Cambodia

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Abstract: *Field experiment with the dimension of 47.7m × 55.5m were performed at Cambodian Agricultural Research and Development Institute (CARDI), Cambodia, from July 2013 to May 2014 to calculate the reference and crop evapotranspiration, and collected requirements input data for the CROPWAT model to estimate the rice water requirements of two seasons. Two types of rice crop was taken in this study. Phka Rumdoul rice, 120 days growing period, was observed in rainy season, and Chu'lsa rice, 100 days growing period, was taken in dry season. The rice crop coefficients were divided in two types, Kc (wet) were 1.05, 1.1, 1.2, 1.05, and Kc (dry) were 0.3, 0.5, 1.05, 0.7; in the initial, development, mid-season and late-season stages, respectively. With implementation of CROPWAT model, followed FAO Paper No 56 Penman-Monteith method*

In the rainy season, water requirements of Phka rumdoul rice and average of evapotranspiration are 494 mm and 4 mm/day. In the initial stage, ETc is around 70 mm, but ETc much increases in late-season, approximately 179 mm since there high wind flow, while ETc in the mid-season is around 174 mm, and 72 mm at the development stage. In contrast, water requirements in dry season of Chul'sa rice and average of evapotranspiration are 518 mm and 5 mm/day. In the initial stage, ETc is around 73 mm, but ETc much increases in mid-season, approximately 180 mm, while ETc in the development is around 150 mm, and 116 mm at the late-season stage.

Keywords: Crop water requirement, Rice, Crop coefficient, Evapotranspiration, CROPWAT model

1. INTRODUCTION

Rice is the dominant crop in Cambodian agriculture. It occupies more than 80 percent of cultivated land and is the most important agricultural export commodity. This should be complemented through an appropriate institutional framework to ensure that research centers focus on basic research and varietal development, while private companies focus on the multiplication and sale of certified seed. The improvements in the functioning of water user groups would go a long way to raise productivity and returns. To increase rice productivity in Cambodia, it is necessary to study on improving irrigation management.

The project team has formed and is collaborating well. Especially pleasing is the cooperation and camaraderie developing between Technical Services Centre (Ministry of Water Resources and Meteorology), CARDI (Min of Ag) and Institute of Technology Cambodia (Ministry of Education). This is a very important work of research such as assessing the water need of rice to improve the management of irrigation water and rice yield, saving water consumption, and setting the regular time of rice irrigation. This project is intended to improve the agricultural sector and Cambodian irrigation system to be more developed.

Experiments have been performed over three years to assess the evapotranspiration of rice crop. Yin Ratha (2012) performed experiments on water requirement of Chu'lsa. ricein dry season, and the result of Cropwat model shows that the evapotranspiration required about 619 mm. Song Layheang (2013) used Cropwat Model to estimate the evapotranspiration of two types of rice crop. The results show that Chu'lsa rice (100 days) required the amount of water about 620 mm in dry season, and 175 mm for Phka Rumdoul rice (120 days) in rainy season.

1.1. Rice Irrigation Water Required

The calculation of the irrigation requirements of wetland rice is different from other field crops. Extra irrigation water is required not only to cover evaporation losses but also to compensate for the percolation losses in the inundated fields. Furthermore, prior to transplanting, substantial irrigation water is required for the land preparation and the nursery. Input and calculation procedures will therefore differ from

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those of the crops for which a separate program is included in CROPWAT. Time of irrigation is usually governed by two major conditions namely, (1) water need of crops and (2) availability of irrigation water. Water need of crops is, however the prime consideration to decide the time of irrigation.

2. METHODOLOGY

2.1 CROPWAT model

CROPWAT 8.0 is an application software developed by several scientist (Doorenbos and Pruitt, 1976, 1977; Smith et al., 1991; Smith, 1992, 1993) for irrigation planning and management of the Water Resources Development and Management Service of FAO. CROPWAT is also a Windows based decision support system designed as a tool to help agro-meteorologists, agronomists, and irrigation engineers carry out standard calculations for evapotranspiration and crop water use studies, particularly the design and management of irrigation schemes.

The input data of CROPWAT model includes crop parameters, meteorology, and soil Table (1). The time step of the results can be any convenient one: daily, weekly, decadal or monthly.

Table 1. The input and output data of the CROPWAT model

Data	Input	Output
Climatic	▪ Monthly/decade/daily minimum and maximum temperatures (ºC), or with average temperatures if minimum/maximum temperatures are not available. ▪ Relative humidity (%) or actual vapour pressure (kPa) ▪ Wind speed (km/day) or (m/s) ▪ Sunshine (hours), percentage of daylight (%), or fraction of daylight (fraction)	▪ Reference evapotranspiration (ETo)
Rain	▪ Monthly/decade/daily rainfall (mm)	▪ Effective rainfall (Pe)
Crop	▪ Crop type ▪ Planting date ▪ Crop coefficient (Kc) ▪ Period of each stage (days) ▪ Rooting depth (m); Critical depletion (fraction); Yield response factor; Crop height (m)	▪ Actual crop evapotranspiration ▪ Crop water requirement (ETc) ▪ Irrigation requirement (Irriq)
Soil	▪ Total available soil moisture (FC-WP) (mm/meter) ▪ Maximum rain infiltration rate (mm/day) ▪ Maximum rooting depth (cm) ▪ Initial soil moisture depletion (%) ▪ Initial available soil moisture (mm/meter)	▪ Daily soil moisture deficit ▪ Estimated yield reduction due to crop stress
Irrigation	▪ Irrigation scheduling criteria	▪ Irrigation scheduling

The CROWAT model operates in two modes by using: (1) the FAO Penman–Monteith equation to compute the actual evapotranspiration; (2) the evapotranspiration measurements values. Penman-Monteith method as recommended by the FAO Expert Consultation held in Rome in May 1990 to carry out the reference evapotranspiration calculation because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Data are requested on the following:

- Basic information on the climate station: country name, station name, altitude, latitude and longitude
- Monthly, decade, or daily climatic data on temperature, relative humidity, daily sunshine and wind speed

The crop water requirements (CWR) is calculated as:

$$CWR = ETo * Crop\ Kc \qquad \text{Eq. (1)}$$

The average values of the crop coefficient (Kc) for each time step are estimated through linear interpolation between the Kc values for each crop development stage. In the case that the crop covers only 50% of the area, the ‘‘Crop Kc” values will be half of the Kc values in the crop coefficient data file. For this study, there were used a set of typical rice crop coefficient data files, as provided in the program of CROPWAT (FAO).

To estimate the amount of crop water requirement and to determine irrigation scheduling, it is necessary to have an equivalent daily or monthly value of rainfall data. The intake of rain into the soil is determined on a daily basis and rainfall losses due to deep percolation and surface runoff are estimated according to actual soil moisture content in the root zone. Total rainfall and not effective rainfall is therefore used for the water balance calculation; effective rainfall is calculated over the total growing season.

The effective rainfall will be calculated automatically in CROPWAT with rainfall data and choosing an appropriate method. Four different methodologies are given to determine the effective rainfall. The different options are: (1) fixed percentage of rainfall; (2) dependable rainfall; (3) empirical formula; (4) USDA Soil Conservation Service Method. The empirical formula was used in this study Eq. (2):

$$P_{eff} = 0.6\ P_{tot} + (-10) \text{ for } P_{tot} < 75 \text{ mm}$$
$$P_{eff} = 0.8\ P_{tot} + (-25) \text{ for } P_{tot} > 75 \text{ mm} \qquad \text{Eq. (2)}$$

Where P_{eff} denotes the effective rainfall; P_{tot} the measured (or generated) total daily rainfall.

The following is the daily climatic data of Khmounh Meteorological Station located about 10 km from CARDI was chosen for use in this study: minimum and maximum air temperature, relative humidity, wind speed, sunshine duration and rainfall (Figure 1). The temperature hovers around 15.3 °C and 37.5 °C respectively for the daily minimum and maximum daily temperature while the average relative humidity varies from 52.9% to 86.2%. In addition, the daily wind speed is about 1.4 m / s, and the sun is 0 to 5.4 hours per day. The rain occurs often from May to November as it is the rainy season. The total rainfall for this period is 1535 mm. Since CADRI meteorological station did not work, there will be some inaccurate data because of the long distance between the research field and weather station. The climatic data is taken from 1 June 2013 to 31 May 2014, are used to represent the data at CARDI. The crop is entirely assumed to be planted in two seasons (rainy and dry seas and to cover 100% of the experimental area.

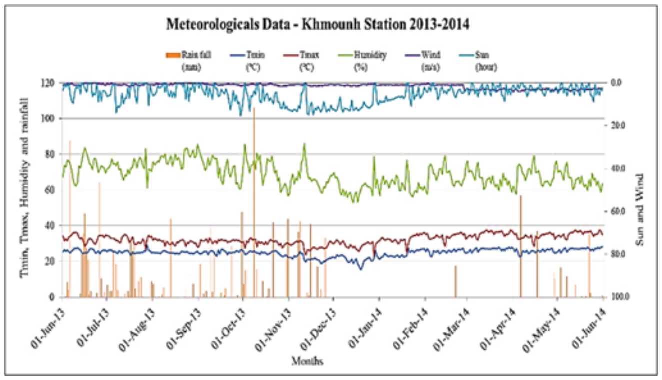

Fig.1. Meteorological Data of Khmounh Station

2.2 Study Area

A small scale experimental field in CARDI was taken. The field is 10 m above the sea level with the dimension 55.5 m × 47.7m. Irrigation system of the field is operated by CARDI.

Soil is a very important component in irrigation system, and it is very necessary to know the characteristics of the soil in rice fields. Thus, soil texture determines the saturation, field capacity, the wilting point infiltration and percolation. These characteristics determine the retained water in the root zone. In this study, soil samples were collected at five locations in the depth of the root zone (20 - 40cm) to represent the soil on the ground. The gain size distribution of the soil grains are usually determined by the sieve analysis and hydrometer test. Determines the size of coarse particles larger than 0.075 mm (75 µ m) diameter, while the hydrometer test, using Stokes' law, smaller soil tests with a 0.075 mm diameter as that are sand, silt and clay. In the analysis of soil, among the five locations, there are four places with the same texture class (sandy loam), so that the soil in this area is supposed to be loamy sand that is in the class of light soil. After the soil characteristics (wilting point, conductivity field capacity, saturation, water availability, and water saturation) are obtained from the SPAW model (Table 2).

Table 2. Soil parameter of CARDI's field

Loamy sand			
General soil data		Additional soil data for rice calculations	
Total available soil moisture (FC-WP) (mm/m)	70	Drainable porosity (SAT-FC) (%)	30
Maximum infiltration rate (mm/day)	24	Critical depletion for pudding cracking (mm WD)	0.4
Maximum rooting depth (cm)	900	Water available at planting (mm WD)	0
Initial soil moisture depletion (%)	0	Maximum water depth (mm)	200

2.3 Rice Crop Factor

In the study of water needs of rice, both Pka Rumdoul rice and Chu'lsar rice were sown directly. Phka Rumdoul (120 days) was grown from August 01 to November 28, 2013, and Chul'sa (100 days) was grown from February 01 to May 11, 2014. Crop parameters are shown at below tables.

Table 3. Each stages crop factor of Phka Rumdoul rice

Phka Rumdoul (120 days)					
Stage	Land Pre	Initial	Devel	Mid-season	Late season
Period (day)	15	20	30	40	30
Kc (dry)	0.3	0.5	1.05	1.05	0.7
Kc (wet)	1.05	1.1	1.2	1.02	1.05
Rd*	-	0.1	0.6	0.6	0.6
Pd*	0.4	-	-	-	-
Cd*	-	0.2	0.2	0.2	0.2
Ky*	-	1	1.09	1.32	0.5
Ch*	-	-	-	1	1

** Rd, Rooting depth (m); Pd, Puddling depth (m); Cd, Critical depletion (m); Ky, Yield response factor; Ch, Crop height (m)*
Source: Final report of Mr. YIN Ratha, 2012 and CROPWAT Rice crop session data

Table 4**.** Each stages crop factor of Chu'lsa rice

Chu'lsa (100 days)					
Stage	LandPre	Initial	Devel	Mid-season	Late season
Period (day)	15	20	30	30	20
Kc (dry)	0.3	0.5	1.05	1.05	0.7
Kc (wet)	1.05	1.1	1.2	1.2	1.05
Rd*	-	0.1	0.6	0.6	0.6
Pd*	0.4	-	-	-	-
Cd*	-	0.2	0.2	0.2	0.2
Ky*	-	1	1.09	1.32	0.5
Ch*	-	-	-	1	1

**Rd, Rooting depth (m); Pd, Puddling depth (m); Cd, Critical depletion (m); Ky, Yield response factor; Ch, Crop height (m)*

Source: Final report of Mr. YIN Ratha, 2012 and CROPWAT Rice crop session data

3. RESULTS AND DISCUSSION

3.1 Rainy Season (Phka Rumdoul rice)

The rice evapotranspiration (ETc) of Phka Rumdoul rice is equal to 494 mm (without soil preparation phase) during the growth period of 120 days. In the preparation phase of the soil, water (266.5 mm) for irrigation is necessary. This is essential for the soil and the day before planting. In the initial stage, the rice needs only about 34 mm per decade to compensate for the water requirements of crops: it's time for the rice root to install and take the amount of water during the next step. Water needs decrease linearly from 35.2 mm to 36.6 mm at the end of the decade in the growth phase where rice maximum water demand for growth. Then, the water requirement of rice increases by a further 38 mm to 42 mm at the beginning of the phase of mid-season where rice seedlings begin to grow. Finally, the water requirement of rice decreases linearly from 55.4 to 34.5 mm in the phase of the off-season: the period of ripening rice and water demand decreases significantly. Rice is not in action over development, and this is also the time for draining dry the soil profile for harvest. (Table 5).

The largest amount of crop water used of Phka Rumdoul rice is 179 mm, consumed during the late season stage. While the amount of water used by crop in the initial phase is around 70 mm, and 72 mm in the development stage. In the mid-season stage, the amount of water consumption of crop is about 174 mm, higher than the initial and mid-season stages since this stage the plant starts flowering and has 40 days. Furthermore, the amount of water remain increases at the late season just because of high wind flow in November.

Last but not least, the amount of water used would be different because of the duration of each stage too.

Table 5. Crop and irrigation water requirement of Phka Rumdoul rice calculated by CROPWAT model

Crop water requirement of Phka Rumdoul rice in Rainy season							
ETo Station: Khmounh				Crop: Phka Rumdourl			
Rain Station: Khmounh				Planting Date: 1-Aug			
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr.req. mm/dec
Aug	1	Init	1.1	3.46	34.6	6.6	28
Aug	2	Init	1.1	3.49	34.9	60.5	0
Aug	3	Deve	1.1	3.2	35.2	11.7	23.5
Sep	1	Deve	1.1	3.66	36.6	44.5	0
Sep	2	Mid	1.09	3.81	38.1	19.3	18.8
Sep	3	Mid	1.09	5.34	53.4	54.1	0
Oct	1	Mid	1.09	4.02	40.2	110.9	0
Oct	2	Mid	1.09	4.21	42.1	5.4	36.7
Oct	3	Late	1.09	5.04	55.4	78.4	0
Nov	1	Late	1.06	4.83	48.3	54.9	0
Nov	2	Late	1.01	4.08	40.8	55.5	0
Nov	3	Late	0.97	4.31	34.5	17.5	12.6
Total (mm)					494.1	519.3	119.6

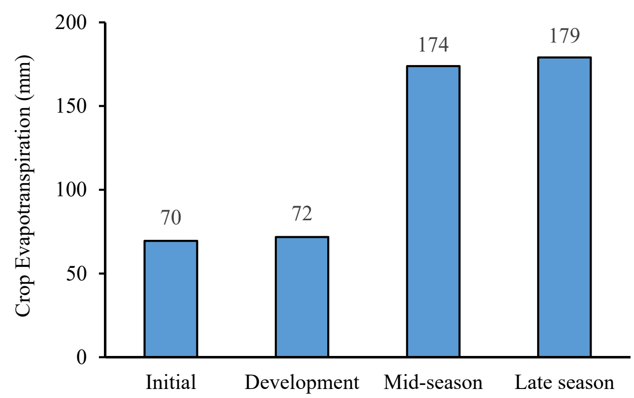

Fig.2.Crop Evapotranspiration in each stage of Phka Rumdoul rice in Rainy season

Table 6. Irrigation schedule of Phka Rumdoul rice in rainy season

ETo Station: khmounh		Crop: Phka Rumdoul	Planting Date:	1-Aug	
Rain Station: Khmounh		Soil: Loamy sand	Harvest Date:	28-Nov	
Date	17-Jul	29-Jul	6-Aug	28-Sep	28-Nov
Day	-14	-2	6	59	End
Stage	PrePu	Puddl	Init	Mid	End
Rain (mm)	31.8	0	0	0	0
Ks (fract.)	1	1	1	1	1
Eta (%)	100	100	100	100	0
Puddl state	Prep	Prep	OK	OK	OK
Percol. (mm)	6.4	4.2	2.9	2.9	0
Depl.SM (mm)	0	0	0	0	0
Net Gift mm	95.4	154.8	97.4	99.9	-
Loss (mm)	0	0	0	0	-
Depl.SAT (mm)	95.4	104.8	-2.6	-0.1	-

Irrigation is applied to the field based on the irrigation time, and precipitation and a fixed depth of water of 100 mm, which corresponds to the intended depth to irrigate the field. This irrigation recharges at a fixed depth, 200 mm of water to compensate for the loss by evapotranspiration and percolation. These fixed levels can be defined in the model CROPWAT. The amount of water for irrigation is linked to crop water need, percolation and effective precipitation. Furthermore, the amount of water for irrigation will be reduced when there is rain. In this case, the water depth level of irrigation water will be less than 200 mm. In Table 5 is listed on the schedule of irrigation applied to plant rice Rumdoul since the beginning of the pre-puddling at the end of the date of irrigation.

3.2 Dry Season (Chul'sa Rice)

The water needs of crops Chu'lsa from initial stages to the late season of the growing period of 100 days is 517.7 mm. During the initial phase, the water used of crop increases slowly from 35.6 mm to 37.1 mm per decade. At the first decade of the development stage, the crop evapotranspiration is 37 mm per decade and starts to increase to 59.4 mm per decade at the end of this phase. The water need of crop remains increase to 70.6 mm per decade at the first decade of mid-season, and decrease to 52.6 mm per decade at the end of the mid-season stage. It is also due to evaporation caused by meteorological factors. Finally, the water demand of rice crop begins decreased dramatically from 59.6 to 5.7 mm per decade at the second decade of late season. Moreover, at the last decade of late season is the harvest time, and the water in the field ought to be empty or drained. (Table 7).

Table 7. Crop and irrigation water requirement of Chul'sa rice calculated by CROPWAT model

ETo Station: Khmounh					Crop: Chu'lsa		
Rain Station: Khmounh					Planting Date: 1-Feb		
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Feb	1	Init	1.1	3.56	35.6	0	35.6
Feb	2	Init	1.1	3.71	37.1	0	37.1
Feb	3	Deve	1.11	4.62	37	7.2	29.8
Mar	1	Deve	1.14	5.33	53.3	0	53.3
Mar	2	Deve	1.16	5.94	59.4	0	59.4
Mar	3	Mid	1.18	6.42	70.6	0	70.6
Apr	1	Mid	1.18	5.63	56.3	37.3	19
Apr	2	Mid	1.18	5.26	52.6	21.3	31.3
Apr	3	Late	1.15	5.96	59.6	11.4	48.2
May	1	Late	1.07	5.05	50.5	14.4	36.1
May	2	Late	1.03	5.68	5.7	0.1	5.7
Total (mm)					517.7	91.7	426.1

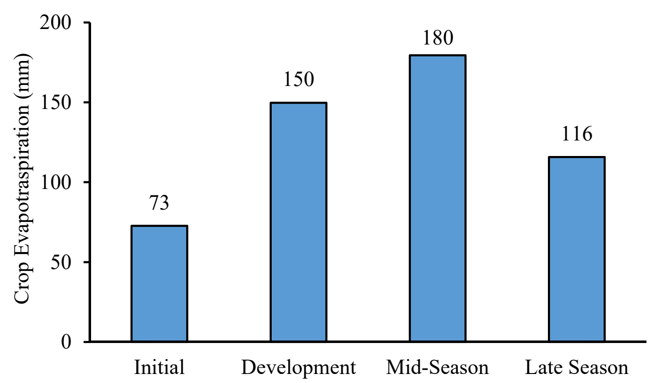

Fig. 3.Crop Evapotranspiration in each stage of Chu'lsa rice in dry season

The crop water use of Chu'lsa rice in dry season in different stages. It shows that rice crop needs less water in the initial stage, around 73 mm, but it needs water the most with approximation of 180 mm in mid-season since during this stage is in the month of April, the hottest month of dry season. While the amount of crop water need in development is around 150 mm, and late season stage is around 116 mm. However, if compared in period of these two stages, the water used in development stage is greater than in the late season stage since the rainy season is starting at the month of May in late season.

The irrigation is applied to the field based on the irrigation time, and precipitation and a fixed depth of water of 100 mm, which corresponds to the intended depth to irrigate the field. This irrigation recharges at a fixed depth, 200 mm of water to compensate for the loss by evapotranspiration and percolation. These fixed levels can be defined in the model CROPWAT. The amount of water for irrigation is linked to crop water need, percolation and effective precipitation. Furthermore, the amount of water for irrigation will be reduced when there is rain. In this case, the water depth level of irrigation water will be less than 200mm.

Table 8. Irrigation schedule of Chu'lsa rice in dry season

ETo Station: Khmounh	Crop: Chu'lsa			Planting Date : 1-Feb						
Rain Station: Khmounh	Soil: Loamy sand			Harvest Date : 11-May						
Date	17-Jan	29-Jan	4-Feb	19-Feb	6-Mar	17-Mar	28-Mar	15-Apr	6-May	11-May
Day	-14	-2	4	19	34	45	56	74	95	End
Stage	Pre	Pud	Init	Init	Dev	Dev	Mid	Mid	End	End
Rain mm	0	0	0	0	0	0	0	0	0.2	0
Ks fract	1	1	1	1	1	1	1	1	1	1
Eta (%)	100	100	100	100	100	100	100	100	100	0
Puddl state	Prep	Prep	OK	OK	OK	OK	OK	OK	OK	OK
Percol. (mm)	0	1	2.9	2.9	2.9	2.9	2.9	2.9	2.9	0
Depl. SM (mm)	1	0	0	0	0	0	0	0	0	0
Net Gift (mm)	121.5	167.3	99.8	97.7	98.8	95.6	99.9	96.2	98.9	
Loss (mm)	0	0	0	0	0	0	0	0	0	
Depl. SAT (mm)	120	117.3	-0.2	-2.3	-1.2	-4.4	-0.1	-3.8	-1.1	

4. CONCLUSION

In conclusion, the results from the CROPWAT computation are acceptable for the calculation of crop water requirement and irrigation water need. For amount of rice water use in rainy season of Phka Rumdoul rice, which is planted from August 01, 2013 to November 28, 2013, is around 494 mm during 120 days. The rice water use of Chulsa rice in dry season, which is planted from February 01, 2014 to May 11, 2014, is around 518 mm in the period of 100 days. Hence, the rice water requirement is between 450 mm 700 mm for the total of growing period (FAO, 1986). CROPWAT can be used to compute the crop water requirement in all season and gives the acceptable results to the experimental field (CARDI) of different types of rice crop. Moreover, this model also has capabilities to calculate and estimate irrigation water requirement, irrigation scheduling as well as the scheme of irrigation.

After collaborating in this research, some recommendations to get the accuracy are made:

- The research should do on all kind of rice crop in order to determine the accurate crop water requirement.
- The meteorological station should be installed as more as possible.
- It is important to choose the right method to estimate effective rainfall, and scheduling since it is related to the amount of water irrigation as well as the productivity of crop yield.
- Before running CROPWAT, the user should check all needed data such as meteorological data, rainfall data, soil and crop data, especially, the error of the values, and also the unit of data.
- CLIMWAT data can be used to simulate in CROPWAT 8.0 as meteorological data did too.

Good management in irrigation is very crucial. Providing water to the crop in adequate amount, and timely irrigation enhances the crop yields and productivity. Moreover, the water will be saved or be not wasted. Since the water is well managed, irrigation system will be extended, and when an extension is implemented, more and more job opportunities simultaneously happen. This will lead to poverty reduction in Cambodia, which is a developing country mostly depending on agriculture sector. We believe that the improving of irrigation system will help our farmer to increase their crop productivities for internal consumption and as well as external exportation of our agricultural products to the world and bring our country into sustainable development.

Acknowledgement:

We would also like to acknowledge with much appreciation of "Australia supported by Center of International Agricultural Research" (ACIAR), and "Commonwealth Scientific and Industrial Research Organization" (CSIRO) from Australia for funding and technical supporting for this project called "Improved Water Management to Increase Rice Productivity in Cambodia" N° LWR/2009/046.

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