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ASSESSMENT OF WATER REQUIREMENT OF TEN SELECTED CROPS CULTIVATED IN CESTOS RIVER BASIN GREENVILLE, LIBERIA USING THE CROPWAT 8.0 SOFTWARE

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***Abstract* -Water is the most important factor for agriculture, and with climate change, the need for efficient irrigation water for crops is increasing. Irrigation water supplies are dwindling and shortages have been reported in many parts of the world. To meet basic human needs, the increase in water consumption due to rapid population growth requires the expansion of food production through irrigation and industrial production and as such, this study aims to determine the crop water requirement as well as the irrigation schedule of ten crops; potatoes, bananas, mangos, rice, groundnut, pepper, cabbage, tomato, maize, and vegetables in the Cestos River Basin, Greenville Sinoe County, Republic of Liberia. Calculations of the crop water and irrigation requirements were carried out using CROPWAT version 8.0. The climatic data used for the calculations were obtained from the Climwat 2.0 software from the Greenville meteorological station in Sinoe County. The results of this study show a method of determining the irrigation water requirements of ten selected crops using the CROPWAT 8.0 model and the CLIMWAT 2.0 software, where rainfall was not taken into account, and as such, results showed that the ETO ranges from 3.18mm/day to 4.02mm/day and effective rainfall ranges from 102.4mm to 197.1; mango had the highest crop water requirement of 1228 mm, while vegetable had the lowest crop water requirement of 288.1 mm. The model predicted the daily, decadal, irrigation schedule as well as monthly crop water requirement at different growing stages of the ten selected crops; potatoes, bananas, mangos, rice, groundnut, pepper, cabbage, tomato, maize, and vegetables in the Cestos River Basin. For the 10 chosen crops at different growth phases, the application of scientific methodologies like CROPWAT and CLIMWAT can reliably determine the crop water requirements and provide irrigation plans and monthly crop water requirements that farmers can accept. In order to save water and meet crop water requirements, farmers can use the study's findings as a guide when deciding how frequently and how much to irrigate the crops that are the subject of the study. Water resource planners can also use these findings when making future plans.**

***Keywords*: Crop water requirement, irrigation schedule, Cropwat 8.0 model, water.**

I. INTRODUCTION

Water is the most important factor for agriculture, and with climate change, the need for efficient irrigation water for crops is increasing. Irrigation water supplies are dwindling and shortages have been reported in many parts of the world. To meet basic human needs, the increase in water consumption due to rapid population growth requires the expansion of food production through irrigation and industrial production. When rainfall is insufficient, the main purpose of irrigation is to provide water to maintain plant transpiration (ET). The lower yield is due to the uneven and erratic distribution of monsoons, as well as the water pressure of the soil during the summer. For successful planning, accurate information is needed on the crop's water requirements, with watering drawn depending on the crop, soil type and weather conditions. Water balance, crop water and irrigation needs of different crops in the area are ultimately determined by precipitation and transpiration. Water requirements for crops are determined by climate, area and type of crop, soil type, growing season and frequency of crop production (FAO, 2009 & George et al., 2000). Crop coefficient (Kc) and potential transpiration value are two factors that affect the water requirement of crops (ET0). Evapotranspiration is the combination of two processes within which water is lost by evaporation from the soil surface and transpiration from plants. The CROPWAT 8.0 model was used to categorize demand (crop water requirements) of main crops in the Cestos River Basin using long-term meteorological data (FAO, 2009). The Food and Agriculture Organization (FAO) created the CROPWAT software application to aid irrigation engineers and

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agronomists in doing common calculations for water irrigation studies, as well as in the management and design of irrigation systems (Salam et al., 2019). CROPWAT helps with irrigation planning by estimating crop evapotranspiration, crop water requirements, and irrigation schedules with various cropping patterns (Kuo et al., 2006),However; there are some main functions of CROPWAT, they are;

- To calculate: Reference evapotranspiration, crop water requirements and crop irrigation requirements.
- To develop: irrigation schedules under various management conditions and scheme water supply

The FAO Penman-Monteith method was employed in this study since it is the only recommended method for calculating reference evapotranspiration. Data on radiation, air temperature, air humidity, and wind speed are required by the FAO Penman Monteith technique. Irrigation schedules for different crops should be location-specific, taking into account soil types and agro-ecological circumstances (Solomon et al., 2018). Cestos River Basin has an average of 185 rainy days each year. The town's coolest month is 24 degrees Celsius, while its warmest month averages 27 degrees Celsius. Greenville is Liberia's third-largest port. The port features two quays for berthing facilities on the inner side of the breakwater (70 and 180 meters long, respectively), with an existing water depth of 6 meters below chart datum. CROPWAT 8.0 is a widely used method by scientists to estimate crop evapotranspiration, CWR, and irrigation scheduling. There is a paucity of information on crop water requirements for potatoes, bananas, mangos, rice, groundnut, pepper, cabbage, tomato, maize, and vegetables grown in the Cestos River Basin, which can be computed and used to schedule irrigation for these crops and as such, this study aims to determine the crop water requirement as well as the irrigation schedule of ten crops; potatoes, bananas, mangos, rice, groundnut, pepper, cabbage, tomato, maize, and vegetables in the Cestos River Basin, Greenville Sinoe County, Republic of Liberia.

Selected Crops to be Cultivated in the Cestos River Basin

1.	**Potatoes**	
2.	**Banana**	
3.	**Mango**	
4.	**Rice**	
5.	**Groundnut**	
6.	**Sweet Pepper**	
7.	**Cabbage**	
8.	**Tomato**	
9.	**Maize**	
10.	**Vegetable**	

II. MATERIALS AND METHODS

2.1 Study Area

The study area, Cestos River Basin in Sinoe County, which is located in south-eastern Liberia. It's roughly 150 kilometres southeast of Monrovia. The population was 16,434 according to the 2008 national census. The British Museum now houses a trove of bronze Kru money rings unearthed in the Cestos River near Greenville. The Mississippi Colonization Society colonists constructed the town around 1838. Part of the colony of Mississippi in Africa during the time (now Sinoe County). The Liberian Civil War destroyed the town, but it was rebuilt around a port for the local timber business. Lumber, rubber, and agricultural products were the town's principal exports prior to the civil war. Near the town is the Sapo National Park. Greenville to Monrovia and Harper is served by boats. Greenville has an average of 185 rainy days each year. The town's coolest month is 24 degrees Celsius, while its warmest month averages 27 degrees Celsius. Greenville is Liberia's third-largest port. The port features two quays for berthing facilities on the inner side of the breakwater (70 and 180 meters long, respectively), with an existing water depth of 6 meters below chart datum.

Figure 1. Cestos River Basin

Source,https://lhsliberia.com/wp-content/uploads/Appendix-15-08

2.2 Determination of Crop Water Requirement

Crop water requirement is the quantity of water required to replace what is lost from a cropped field due to ET, expressed in millimetres per day. Crop water requirement is calculated using crop evapotranspiration (ETc), which may be estimated using the equation below.

ETc = Kc X ET0, where the crop coefficient is denoted by Kc. It is the ratio of the crop ETc to the ET0, and it is an integration of the effects of four fundamental qualities that distinguish the crop from reference grass: crop albedo

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(reflectance), crop height, canopy resistance, and evaporation from the soil.

The crop's Kc will fluctuate over the developing period, which can be classified into four stages: beginning, crop development, mid-season, and late season, due to ET fluctuations over the growth stages. Based on FAO Irrigation and Drainage Paper 56, the reference evapotranspiration ET0 was estimated using the FAO Penman- Monteith method and FAO decision support software –CROPWAT 8.0. (FAO, 2002). The FAO CROPWAT program (FAO, 2009) includes processes for calculating reference crop evapotranspiration and crop water requirements, as well as crop water consumption simulations under varied climate, crop, and soil conditions (www.fao.org).

Calculations of the crop water and irrigation requirements were carried out using CROPWAT version 8. The climatic data used for the calculations were obtained from the Climwat 2.0 software in which ten years data was used from the Greenville meteorological station in Sinoe County. The process or processes of obtaıning the crop water requirements of the ten selected crops can be summarized as follow; firstly the climatological data was obtained from the CLIMWAT 2.0 software and inputed into the rainfall section for the sore purpose of estimated the monthly rainfall; after which the crop characteristic data were obtained from the FAO file within the CROPWAT software, knowing the type of soil was essential, and as such, soil characteristic data was also inputed from the FAO file within the CROPWAT software as well as obtaining the value of daily Crop water needs(ETC), ETC/decade and also analysing the irrigation scheduling.

2.3 Irrigation Water Requirement (IR)

The following equation can be used by the CROPWAT Model to calculate the root zone's daily water balance up to the point of day's end root zone depletion:

$Dr,i = Dr,i-1 - (P - ROi) - Ii - CRi + ETci + DPi$ (4) where Dr,i is the root zone depletion at the day's end i (mm), Dr,i−1 is the water content in the root zone at the previous day's end (mm), Pi is the precipitation on day i (mm), ROi is the surface soil runoff on day i (mm), Ii is the net irrigation depth on day i which infiltrates the soil (mm), Cri is the capillary rise from the groundwater table on day i (mm), ETci is the crop evapotranspiration on day i (mm), and DPi is the lost water of the root zone on day i (mm).

2.3 Meteorological data

The Meteorological data was collected from Greenville meteorological station located in Sinoe County, Liberia with latitude of 5.16N, longitude of -9.08 0E and altitude of 5m have been presented in table 1. The meteorological parameters used for calculation of ET0 are latitude, longitude and altitude of the station, maximum and minimum temperature (oC), maximum and minimum relative humidity (%), wind speed (km/day) and sunshine hours which was collected and the average values have been fed to the model. Rainfall data collected from the same station in Climwat 2.0 was fed to the software which generated the effective rainfall data.

2.4 Crop data

CROPWAT requires the crop data like, crop coefficient, Kc values (initial, mid and late growth stages), rooting depth, and length of plant growth stages, critical depletion and yield response factor and as such, these data were obtaıned from FAO.

2.5 Soil data

The Soil type in this area is black clay soil, and as such, the soil data was generated from FAO within the CROPWAT software in order to get some general soil data like total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture.

2.6 Irrigation Schedule

The irrigation scheduling controls how much water to irrigate and when to irrigate. The ET0, crop water requirement, and irrigation requirements are calculated by the CROPWAT model to produce irrigation schedules under various administrative situations and water supply plans.

III. RESULTS AND DISCUSSION

The crop water requirement was calculated using Greenville's historical weather data, which was exported from the CLIMWAT software (Table 1). Details such as country (Liberia), climatic station (Greenville), type of crop, date of cultivation, and soil type (Black clay soil) were entered into the CROPWAT software. Once the data was loaded into the model, the program automatically calculated the ET0, effective rainfall, and total irrigation demand for each of the 10 crops. At different phases of the ten selected crops (potatoes, banana, mango, rice, groundnut, and pepper cabbage, and tomato, maize and vegetable) growth, the model predicted daily, decadal, and monthly crop water requirements as well as the irrigation schedule of the crops.

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Table 1. Greenville Climatic data

Country: Location 3 Station: GREENVILLE
Altitude: 5 m. Latitude: 5.16 °N Longitude: 9.08 °W

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	21.0	32.1	75	95	5.2	16.1	3.63
February	20.2	31.8	71	95	5.3	17.1	3.87
March	20.5	32.1	72	95	5.3	17.7	4.02
April	21.0	31.0	75	95	5.1	17.2	3.84
May	21.1	30.8	75	112	4.5	15.7	3.65
June	21.0	29.6	78	181	3.6	14.0	3.46
July	20.7	29.2	78	216	2.6	12.7	3.36
August	20.8	28.8	80	216	2.2	12.5	3.24
September	21.5	28.3	82	181	2.7	13.5	3.18
October	20.8	29.6	78	130	4.3	15.6	3.51
November	20.5	31.5	74	130	4.9	15.8	3.71
December	21.0	30.8	78	95	4.3	14.5	3.23
Average	**20.8**	**30.5**	**76**	**137**	**4.2**	**15.2**	**3.56**

The chart above shows the historical climatıc data for Greenville meteorological station which was exported from the CLIMWAT 2.0 software and was inputed into the CROPWAT software. The chart shows seven different parameters; minimum, maximum temperature, humidity, wind, sun, radius, and ETo (evapotranspiration) with the various ranges, were in the ETo ranges from 3.18mm/day to 4.02mm/day.

Table 2. Monthly rainfall data for Greenville

Station: GREENVILLE Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	129.0	102.4
February	139.0	108.1
March	223.0	143.4
April	193.0	133.4
May	555.0	180.5
June	721.0	197.1
July	264.0	151.4
August	193.0	133.4
September	597.0	184.7
October	503.0	175.3
November	323.0	157.3
December	292.0	154.2
Total	**4132.0**	**1821.2**

The table above shows the monthly rainfall which was obtained from the CROPWAT software, however, from the beginning, the effective rainfall which is the difference between the rainfall and the actual evapotranspiration was set at zero in the software.

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Crop Water Requirement of the Ten (10) selected crops can be seen below:

Table 3: Crop water requirement for Potato

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: Potato
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.50	1.79	14.3	0.0	14.3
Jun	1	Init	0.50	1.76	17.6	0.0	17.6
Jun	2	Deve	0.51	1.77	17.7	0.0	17.7
Jun	3	Deve	0.68	2.32	23.2	0.0	23.2
Jul	1	Deve	0.88	3.00	30.0	0.0	30.0
Jul	2	Mid	1.08	3.62	36.2	0.0	36.2
Jul	3	Mid	1.12	3.73	41.0	0.0	41.0
Aug	1	Mid	1.12	3.68	36.8	0.0	36.8
Aug	2	Mid	1.12	3.63	36.3	0.0	36.3
Aug	3	Mid	1.12	3.61	39.7	0.0	39.7
Sep	1	Late	1.04	3.34	33.4	0.0	33.4
Sep	2	Late	0.90	2.87	28.7	0.0	28.7
Sep	3	Late	0.76	2.51	25.1	0.0	25.1
					380.0	0.0	380.0

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 380.0mm/dec as well as this 380.0mm/dec for crop water requirement. The highest irrigation required is 41.0mm which is as a result of the development period of the crop, and as such, water is highly required by the crop to sustain its development. The lowest water required was 14.3mm/dec in the month of May.

Table 4: Irrigation schedule for Potatoe

Totals:

Total gross irrigation	45.4	mm	Total rainfall	1879.	mm
Total net irrigation	31.7	mm	Effective rainfall	397.7	mm
Total irrigation losses	0.0	mm	Total rain loss	1482.	mm
Actual water use by crop	376.9	mm	Moist deficit at harvest	7.5	mm
Potential water use by crop	377.5	mm	Actual irrigation requirement	-20.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	21.2	%
Deficiency irrigation schedule	0.2	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	1.3	0.0	0.0	0.0	0.2	%
Yield response factor	0.45	0.80	0.80	0.30	1.10	
Yield reduction	0.6	0.0	0.0	0.0	0.2	%
Cumulative yield reduction	0.6	0.6	0.6	0.6		%

The total gross is 45.4mm, net irrigation 37.7mm; the total irrigation loss for the potato crop was found to be 0mm. The actual water used by the crop was 376.9mm while the potential water use is 377.5mm. The respective crop yield response stood 1.10% ;reason why there was no need for additional irrigation by this crop can be attributed to different factors like soil water retaining capacity, the soil type and how the crop responds to the soil and; different types of crops respond differently to several soil types.

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Table 5: Crop water requirement for Banana

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: BANANA 1st year
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.50	1.79	14.3	0.0	14.3
Jun	1	Init	0.50	1.76	17.6	0.0	17.6
Jun	2	Init	0.50	1.73	17.3	0.0	17.3
Jun	3	Init	0.50	1.71	17.1	0.0	17.1
Jul	1	Init	0.50	1.70	17.0	0.0	17.0
Jul	2	Init	0.50	1.68	16.8	0.0	16.8
Jul	3	Init	0.50	1.66	18.3	0.0	18.3
Aug	1	Init	0.50	1.64	16.4	0.0	16.4
Aug	2	Init	0.50	1.62	16.2	0.0	16.2
Aug	3	Deve	0.52	1.66	18.3	0.0	18.3
Sep	1	Deve	0.55	1.76	17.6	0.0	17.6
Sep	2	Deve	0.58	1.86	18.6	0.0	18.6
Sep	3	Deve	0.62	2.03	20.3	0.0	20.3
Oct	1	Deve	0.65	2.21	22.1	0.0	22.1
Oct	2	Deve	0.68	2.39	23.9	0.0	23.9
Oct	3	Deve	0.72	2.56	28.2	0.0	28.2
Nov	1	Deve	0.75	2.74	27.4	0.0	27.4
Nov	2	Deve	0.78	2.91	29.1	0.0	29.1
Nov	3	Deve	0.82	2.90	29.0	0.0	29.0
Dec	1	Deve	0.85	2.88	28.8	0.0	28.8
Dec	2	Deve	0.88	2.85	28.5	0.0	28.5
Dec	3	Deve	0.92	3.08	33.9	0.0	33.9
Jan	1	Deve	0.95	3.33	33.3	0.0	33.3
Jan	2	Deve	0.98	3.58	35.8	0.0	35.8
Jan	3	Deve	1.02	3.79	41.7	0.0	41.7
Feb	1	Mid	1.04	3.95	39.5	0.0	39.5
Feb	2	Mid	1.04	4.04	40.4	0.0	40.4
Feb	3	Mid	1.04	4.09	32.7	0.0	32.7
Mar	1	Mid	1.04	4.14	41.4	0.0	41.4
Mar	2	Late	1.04	4.18	41.8	0.0	41.8
Mar	3	Late	1.02	4.02	44.2	0.0	44.2
Apr	1	Late	0.98	3.81	38.1	0.0	38.1
Apr	2	Late	0.94	3.62	29.0	0.0	29.0
					894.6	0.0	894.6

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 894.6mm/dec as well as this 894.6mm/dec for crop water requirement. The highest irrigation required is 44.2mm in the month of March at late development stage. The lowest water required was 14.3mm/dec in the month of May.

Table 6: Irrigation Schedule for Banana

Totals:

Total gross irrigation	48.7	mm	Total rainfall	3589.	mm
Total net irrigation	34.1	mm	Effective rainfall	943.3	mm
Total irrigation losses	0.0	mm	Total rain loss	2646.	mm
Actual water use by crop	891.0	mm	Moist deficit at harvest	3.6	mm
Potential water use by crop	891.0	mm	Actual irrigation requirement	-52.3	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	26.3	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.00	1.00	1.00	1.00	1.00	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 48.7mm, net irrigation 34.1mm; the total irrigation loss for the banana crop was found to be 0mm. The actual water used by the crop was 891.0mm while the potential water use is 891.0mm. The respective crop yield response stood 1.00% ;reason why there was no need for additional irrigation by this crop can be attributed to different factors like soil water retaining capacity, the soil type and how the crop responds to the soil and; different types of crops respond differently to several soil types.

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Table 7: Crop water requirement for Mango

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: MANGO
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.82	2.93	23.5	0.0	8.8
Jun	1	Init	0.90	3.17	31.7	0.0	31.7
Jun	2	Init	0.90	3.11	31.1	0.0	31.1
Jun	3	Init	0.90	3.08	30.8	0.0	30.8
Jul	1	Init	0.90	3.05	30.5	0.0	30.5
Jul	2	Init	0.90	3.03	30.3	0.0	30.3
Jul	3	Init	0.90	2.99	32.9	0.0	32.9
Aug	1	Init	0.90	2.95	29.5	0.0	29.5
Aug	2	Init	0.90	2.92	29.2	0.0	29.2
Aug	3	Deve	0.91	2.92	32.1	0.0	32.1
Sep	1	Deve	0.92	2.94	29.4	0.0	29.4
Sep	2	Deve	0.93	2.97	29.7	0.0	29.7
Sep	3	Deve	0.95	3.11	31.1	0.0	31.1
Oct	1	Deve	0.96	3.26	32.6	0.0	32.6
Oct	2	Deve	0.97	3.41	34.1	0.0	34.1
Oct	3	Deve	0.98	3.53	38.8	0.0	38.8
Nov	1	Deve	1.00	3.65	36.5	0.0	36.5
Nov	2	Mid	1.01	3.76	37.6	0.0	37.6
Nov	3	Mid	1.02	3.62	36.2	0.0	36.2
Dec	1	Mid	1.02	3.45	34.5	0.0	34.5
Dec	2	Mid	1.02	3.28	32.8	0.0	32.8
Dec	3	Mid	1.02	3.42	37.7	0.0	37.7
Jan	1	Mid	1.02	3.56	35.6	0.0	35.6
Jan	2	Mid	1.02	3.70	37.0	0.0	37.0
Jan	3	Mid	1.02	3.78	41.6	0.0	41.6
Feb	1	Mid	1.02	3.86	38.6	0.0	38.6
Feb	2	Late	1.02	3.94	39.4	0.0	39.4
Feb	3	Late	1.00	3.93	31.4	0.0	31.4
Mar	1	Late	0.98	3.90	39.0	0.0	39.0
Mar	2	Late	0.96	3.86	38.6	0.0	38.6
Mar	3	Late	0.94	3.72	40.9	0.0	40.9
Apr	1	Late	0.92	3.58	35.8	0.0	35.8
Apr	2	Late	0.90	3.44	34.4	0.0	34.4
Apr	3	Late	0.87	3.30	33.0	0.0	33.0
May	1	Late	0.85	3.17	31.7	0.0	31.7
May	2	Late	0.83	3.04	30.4	0.0	30.4
May	3	Late	0.82	2.93	8.8	0.0	8.8
					1228.9	0.0	1214.3

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 1214.3mm/dec as well as this 1228.9mm/dec for crop water requirement. The highest irrigation required is 41.6mm in the month of January. The lowest water required was 8.8mm/dec in the month of May.

Table 8:Irrigation Schedule for Mango

Totals:

Total gross irrigation	0.0	mm	Total rainfall	4131.	mm
Total net irrigation	0.0	mm	Effective rainfall	2125.	mm
Total irrigation losses	0.0	mm	Total rain loss	2006.	mm
Actual water use by crop	1226.0	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	1226.0	mm	Actual irrigation requirement	-899.	mm
Efficiency irrigation schedule	-	%	Efficiency rain	51.5	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.80	0.80	0.80	0.80	0.80	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the mango crop was found to be 0mm. The actual water used by the crop was 1226.0mm while the potential water use is 1226.0mm. The respective crop yield response stood 0.80%.

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Table 9: Crop water requirement for Rice

CROP WATER REQUIREMENTS

ETo station: GREENVILLE — Crop: Rice
Rain station: GREENVILLE — Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Apr	3	Nurs	1.20	0.45	3.2	0.0	3.2
May	1	Nurs/LPr	1.11	2.90	29.0	0.0	120.2
May	2	Nurs/LPr	1.06	3.89	38.9	0.0	122.0
May	3	Init	1.09	3.91	43.0	0.0	93.6
Jun	1	Init	1.10	3.87	38.7	0.0	38.7
Jun	2	Deve	1.11	3.83	38.3	0.0	38.3
Jun	3	Deve	1.13	3.87	38.7	0.0	38.7
Jul	1	Deve	1.15	3.91	39.1	0.0	39.1
Jul	2	Mid	1.17	3.92	39.2	0.0	39.2
Jul	3	Mid	1.17	3.88	42.7	0.0	42.7
Aug	1	Mid	1.17	3.83	38.3	0.0	38.3
Aug	2	Mid	1.17	3.78	37.8	0.0	37.8
Aug	3	Late	1.14	3.67	40.4	0.0	40.4
Sep	1	Late	1.08	3.46	34.6	0.0	34.6
Sep	2	Late	1.02	3.25	32.5	0.0	32.5
					534.4	0.0	759.4

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 759.4mm/dec as well as this 534.4mm/dec for crop water requirement. The highest irrigation required is 122.0mm in the month of May at early development stage. The lowest water required was 3.2mm/dec in the month of April during the nursery stage.

Table 10: Irrigation Schedule for rice

Totals:

Total gross irrigation	320.9	mm	Total rainfall	2050.	mm
Total net irrigation	224.7	mm	Effective rainfall	1147.	mm
Total irrigation losses	0.0	mm	Total rain loss	902.5	mm
Total percolation losses	698.9	mm			
Actual water use by crop	448.3	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	448.3	mm	Actual irrigation requirement	-699.	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	56.0	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.00	1.09	1.32	0.50	1.10	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 320.9mm, net irrigation 224.7mm; the total irrigation loss for the rice crop was found to be 0mm. The actual water used by the crop was 448.3mm while the potential water use is 448.3mm. The respective crop yield response stood 1.10% ;reason why there was no need for additional irrigation by this crop can be attributed to different factors like soil water retaining capacity, the soil type and how the crop responds to the soil and; different types of crops respond differently to several soil types.

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Table 11: Crop water requirement for Groundnut

CROP WATER REQUIREMENTS

ETo station: GREENVILLE — Crop: Groudnut
Rain station: GREENVILLE — Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.40	1.43	11.5	0.0	11.5
Jun	1	Init	0.40	1.41	14.1	0.0	14.1
Jun	2	Deve	0.41	1.43	14.3	0.0	14.3
Jun	3	Deve	0.58	1.97	19.7	0.0	19.7
Jul	1	Deve	0.78	2.65	26.5	0.0	26.5
Jul	2	Deve	0.99	3.32	33.2	0.0	33.2
Jul	3	Mid	1.12	3.72	40.9	0.0	40.9
Aug	1	Mid	1.12	3.68	36.8	0.0	36.8
Aug	2	Mid	1.12	3.64	36.4	0.0	36.4
Aug	3	Mid	1.12	3.61	39.7	0.0	39.7
Sep	1	Late	1.09	3.48	34.8	0.0	34.8
Sep	2	Late	0.88	2.81	28.1	0.0	28.1
Sep	3	Late	0.66	2.16	21.6	0.0	21.6
					357.6	0.0	357.6

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 357.6mm/dec as well as this 357.6mm/dec for crop water requirement. The highest irrigation required is 40.9mm in the month of July at middle development stage. The lowest water required was 11.5mm/dec in the month of May during the initial stage.

Table 12: Irrigation Schedule for groundnut

Total gross irrigation	0.0	mm	Total rainfall	2146.	mm
Total net irrigation	0.0	mm	Effective rainfall	425.3	mm
Total irrigation losses	0.0	mm	Total rain loss	1721.	mm
Actual water use by crop	430.7	mm	Moist deficit at harvest	5.4	mm
Potential water use by crop	430.7	mm	Actual irrigation requirement	5.4	mm
Efficiency irrigation schedule	-	%	Efficiency rain	19.8	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.60	1.10	0.80	1.05	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the groundnut crop was found to be 0mm. The actual water used by the crop was 430.7mm while the potential water use is 430.7mm. The respective crop yield response stood 1.05%.

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Table 13: Crop water requirement for Tomato

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: Tomato
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.60	2.15	17.2	0.0	17.2
Jun	1	Init	0.60	2.11	21.1	0.0	21.1
Jun	2	Init	0.60	2.07	20.7	0.0	20.7
Jun	3	Deve	0.65	2.21	22.1	0.0	22.1
Jul	1	Deve	0.77	2.62	26.2	0.0	26.2
Jul	2	Deve	0.90	3.03	30.3	0.0	30.3
Jul	3	Deve	1.04	3.44	37.9	0.0	37.9
Aug	1	Mid	1.11	3.65	36.5	0.0	36.5
Aug	2	Mid	1.11	3.61	36.1	0.0	36.1
Aug	3	Mid	1.11	3.58	39.4	0.0	39.4
Sep	1	Mid	1.11	3.56	35.6	0.0	35.6
Sep	2	Late	1.10	3.48	34.8	0.0	34.8
Sep	3	Late	0.99	3.24	32.4	0.0	32.4
Oct	1	Late	0.87	2.94	29.4	0.0	29.4
Oct	2	Late	0.77	2.72	13.6	0.0	13.6
					433.4	0.0	433.4

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 433.4mm/dec as well as this 433.4mm/dec for crop water requirement. The highest irrigation required is 37.9mm in the month of July at development stage. The lowest water required was 13.6mm/dec in the month of October during the late stage.

Table 14: Irrigation Schedule for tomato

Totals:

Total gross irrigation	0.0	mm	Total rainfall	2146.	mm
Total net irrigation	0.0	mm	Effective rainfall	425.3	mm
Total irrigation losses	0.0	mm	Total rain loss	1721.	mm
Actual water use by crop	430.7	mm	Moist deficit at harvest	5.4	mm
Potential water use by crop	430.7	mm	Actual irrigation requirement	5.4	mm
Efficiency irrigation schedule	-	%	Efficiency rain	19.8	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.60	1.10	0.80	1.05	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the Tomato crop was found to be 0mm. The actual water used by the crop was 430.7mm while the potential water use is 430.7mm. The respective crop yield response stood 1.05%

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Table 15: Crop water requirement for Cabbage

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: CABBAGE Crucifers
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.70	2.51	20.1	0.0	20.1
Jun	1	Init	0.70	2.46	24.6	0.0	24.6
Jun	2	Init	0.70	2.42	24.2	0.0	24.2
Jun	3	Init	0.70	2.40	24.0	0.0	24.0
Jul	1	Deve	0.72	2.44	24.4	0.0	24.4
Jul	2	Deve	0.77	2.58	25.8	0.0	25.8
Jul	3	Deve	0.82	2.73	30.0	0.0	30.0
Aug	1	Deve	0.88	2.87	28.7	0.0	28.7
Aug	2	Deve	0.93	3.00	30.0	0.0	30.0
Aug	3	Deve	0.98	3.16	34.7	0.0	34.7
Sep	1	Mid	1.01	3.22	32.2	0.0	32.2
Sep	2	Mid	1.01	3.20	32.0	0.0	32.0
Sep	3	Mid	1.01	3.31	33.1	0.0	33.1
Oct	1	Mid	1.01	3.42	34.2	0.0	34.2
Oct	2	Mid	1.01	3.53	35.3	0.0	35.3
Oct	3	Late	0.97	3.46	38.1	0.0	38.1
Nov	1	Late	0.92	3.36	13.4	0.0	13.4
					484.9	0.0	484.9

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 484.9mm/dec as well as this 484.9mm/dec for crop water requirement. The highest irrigation required is 38.1mm in the month of October at late stage. The lowest water required was 13.4mm/dec in the month of November during the late stage.

Table 17: Irrigation Schedule for Cabbage

Totals:

Total gross irrigation	0.0	mm	Total rainfall	2444.	mm
Total net irrigation	0.0	mm	Effective rainfall	478.2	mm
Total irrigation losses	0.0	mm	Total rain loss	1965.	mm
Actual water use by crop	481.5	mm	Moist deficit at harvest	3.4	mm
Potential water use by crop	481.5	mm	Actual irrigation requirement	3.4	mm
Efficiency irrigation schedule	-	%	Efficiency rain	19.6	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.20	0.40	0.45	0.60	0.95	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the Cabbage crop was found to be 0mm. The actual water used by the crop was 481.5mm while the potential water use is 481.5mm. The respective crop yield response stood 0.95%

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Table 18: Crop water requirement for Maize

CROP WATER REQUIREMENTS

ETo station: GREENVILLE — Crop: MAIZE (Grain)
Rain station: GREENVILLE — Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.30	1.08	8.6	0.0	8.6
Jun	1	Init	0.30	1.06	10.6	0.0	10.6
Jun	2	Deve	0.39	1.34	13.4	0.0	13.4
Jun	3	Deve	0.63	2.16	21.6	0.0	21.6
Jul	1	Deve	0.88	2.98	29.8	0.0	29.8
Jul	2	Mid	1.11	3.72	37.2	0.0	37.2
Jul	3	Mid	1.16	3.85	42.4	0.0	42.4
Aug	1	Mid	1.16	3.80	38.0	0.0	38.0
Aug	2	Mid	1.16	3.76	37.6	0.0	37.6
Aug	3	Late	1.12	3.61	39.8	0.0	39.8
Sep	1	Late	0.88	2.80	28.0	0.0	28.0
Sep	2	Late	0.61	1.93	19.3	0.0	19.3
Sep	3	Late	0.40	1.33	6.6	0.0	6.6
					332.9	0.0	332.9

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 332.9mm/dec as well as this 332.9mm/dec for crop water requirement. The highest irrigation required is 42.4mm in the month of July at middle stage. The lowest water required was 6.6mm/dec in the month of September during the late stage.

Table 19: Irrigation Schedule for Maize

Total gross irrigation	0.0	mm	Total rainfall	1777.	mm
Total net irrigation	0.0	mm	Effective rainfall	328.9	mm
Total irrigation losses	0.0	mm	Total rain loss	1448.	mm
Actual water use by crop	331.6	mm	Moist deficit at harvest	2.7	mm
Potential water use by crop	331.6	mm	Actual irrigation requirement	2.7	mm
Efficiency irrigation schedule	-	%	Efficiency rain	18.5	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.40	0.40	1.30	0.50	1.25	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the Maize crop was found to be 0mm. The actual water used by the crop was 331.6mm while the potential water use is 331.6.mm. The respective crop yield response stood 1.25%

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Table 20: Crop water requirement for Vegetable

CROP WATER REQUIREMENTS

ETo station: GREENVILLE — Crop: Small Vegetables
Rain station: GREENVILLE — Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.70	2.51	20.1	0.0	20.1
Jun	1	Init	0.70	2.46	24.6	0.0	24.6
Jun	2	Deve	0.74	2.56	25.6	0.0	25.6
Jun	3	Deve	0.85	2.90	29.0	0.0	29.0
Jul	1	Deve	0.96	3.25	32.5	0.0	32.5
Jul	2	Mid	1.03	3.45	34.5	0.0	34.5
Jul	3	Mid	1.03	3.41	37.6	0.0	37.6
Aug	1	Mid	1.03	3.37	33.7	0.0	33.7
Aug	2	Late	1.00	3.23	32.3	0.0	32.3
Aug	3	Late	0.94	3.04	18.2	0.0	18.2
					288.1	0.0	288.1

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 288.1mm/dec as well as this 288.1mm/dec for crop water requirement. The highest irrigation required is 37.6mm in the month of July at middle stage. The lowest water required was 18.2mm/dec in the month of August during the late stage.

Table 21: Irrigation Schedule for Vegetable

Totals:

Total gross irrigation	0.0	mm	Total rainfall	1235.	mm
Total net irrigation	0.0	mm	Effective rainfall	276.0	mm
Total irrigation losses	0.0	mm	Total rain loss	959.8	mm
Actual water use by crop	285.1	mm	Moist deficit at harvest	9.1	mm
Potential water use by crop	285.1	mm	Actual irrigation requirement	9.1	mm
Efficiency irrigation schedule	-	%	Efficiency rain	22.3	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.80	0.40	1.20	1.00	1.00	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 0.0mm, net irrigation 0.0mm; the total irrigation loss for the vegetable crop was found to be 0mm. The actual water used by the crop was 285.1mm while the potential water use is 285.1.mm. The respective crop yield response stood 1.00%

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Table 22: Crop water requirement for Sweet Pepper

CROP WATER REQUIREMENTS

ETo station: GREENVILLE
Rain station: GREENVILLE

Crop: Sweet Peppers
Planting date: 24/05

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
May	3	Init	0.60	2.15	17.2	0.0	17.2
Jun	1	Init	0.60	2.11	21.1	0.0	21.1
Jun	2	Init	0.60	2.07	20.7	0.0	20.7
Jun	3	Deve	0.64	2.20	22.0	0.0	22.0
Jul	1	Deve	0.76	2.58	25.8	0.0	25.8
Jul	2	Deve	0.88	2.96	29.6	0.0	29.6
Jul	3	Mid	0.99	3.30	36.3	0.0	36.3
Aug	1	Mid	1.02	3.33	33.3	0.0	33.3
Aug	2	Mid	1.02	3.29	32.9	0.0	32.9
Aug	3	Mid	1.02	3.27	36.0	0.0	36.0
Sep	1	Late	1.00	3.21	32.1	0.0	32.1
Sep	2	Late	0.93	2.95	29.5	0.0	29.5
Sep	3	Late	0.86	2.84	14.2	0.0	14.2
					350.8	0.0	350.8

The table above shows the water required to irrigate the crop monthly and at every interval. The total irrigation required is 350.8mm/dec as well as this 350.8mm/dec for crop water requirement. The highest irrigation required is 36.3mm in the month of July at middle stage. The lowest water required was 18.2mm/dec in the month of September during the late stage.

Table 23: Irrigation Schedule for sweet pepper

Totals:

Total gross irrigation	21.4	mm	Total rainfall	1777.	mm
Total net irrigation	15.0	mm	Effective rainfall	327.3	mm
Total irrigation losses	0.0	mm	Total rain loss	1450.	mm
Actual water use by crop	348.0	mm	Moist deficit at harvest	5.7	mm
Potential water use by crop	348.0	mm	Actual irrigation requirement	20.7	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	18.4	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.40	0.60	1.20	0.60	1.10	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

The total gross is 21.4mm, net irrigation 15.0mm; the total irrigation loss for the sweet pepper crop was found to be 0mm. The actual water used by the crop was 348.0mm while the potential water use is 348.0mm. The respective crop yield response stood 1.10%

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Table 24. Scheme Supply

SCHEME SUPPLY

ETo station: GREENVILLE Cropping pattern: Cestos Basin Crops P
Rain station: GREENVILLE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Potato	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0
2. BANANA 1st year	14.6	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3. MANGO	14.1	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4. Rice	0.0	0.0	0.0	91.0	90.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0
5. Groudnut	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0
6. Sweet Peppers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7. CABBAGE Crucifers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8. Tomato	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9. Small Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10. MAIZE (Grain)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net scheme irr.req.												
in mm/day	0.1	0.1	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
in mm/month	2.9	1.9	0.0	9.1	9.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
in l/s/h	0.01	0.01	0.00	0.04	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Irrigated area (% of total area)	20.0	20.0	0.0	10.0	10.0	0.0	0.0	0.0	30.0	0.0	0.0	0.0
Irr.req. for actual area (l/s/h)	0.05	0.04	0.00	0.35	0.34	0.00	0.00	0.00	0.02	0.00	0.00	0.00

The table above shows the irrigation scheme supply for the ten selected crops in the Cestos River Basin.

IV. CONCLUSION

Irrigation management is critical for maximizing the use of available water resources to suit the varying cropping patterns. The major goal of this paper was to use the CROPWAT 8 irrigation water management model to figure out how much water the 10 crops needed. This model was used to determine the climate, rainfall, soil type, crop water need, irrigation schedule, and irrigation scheme. The results of this study show a method of determining the irrigation water requirements of ten selected crops using the CROPWAT 8.0 model and the CLIMWAT 2.0 software, where rainfall was not taken into account, and as such, results show that the ETO ranges from 3.18mm/day to 4.02mm/day and effective rainfall ranges from 102.4mm to 197.1; mango had the highest crop water requirement of 1228 mm, while vegetable had the lowest crop water requirement of 288.1 mm.For the 10 chosen crops at different growth phases, the application of scientific methodologies like CROPWAT and CLIMWAT can reliably determine the crop water requirements and provide irrigation plans and monthly crop water requirements that farmers can accept. In order to save water and meet crop water requirement, farmers can use the study's findings as a guide when deciding how frequently and how much to irrigate the crops that are the subject of the study. Water resource planners can also use these findings when making future plans.

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