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NEPAD Networks of Centre of Excellence in Water Sciences PHASE II

A C E W A T E R 2 P r o j e c t 2 0 1 6 - 2 0 1 9

Potentials in Agriculture Development and Irrigation Expansion in Zambezi River Basin (ZRB)

Project location	Zambezi River Basin (ZRB)
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Title of the Deliverable	Potentials in agriculture development and irrigation expansion in the ZRB
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Executive Summary

The Zambezi River Basin (ZRB) is among the key water resources of Southern Africa. It sustains the socio-economic livelihoods of a rapidly growing population of over 40 million people. This rapid population growth is coupled with other pressures such as climate change and variability. The water resources of the ZRB are therefore increasingly being stressed due to concerted efforts by the riparian to carter for the needs of the large population against the pressures. Irrigation expansion is an alternative water using activity that is likely to result in additional pressure to the ZRB's water resources. Presently, the ZRB has an estimated total irrigation potential of over 30 thousand km^2, of which only 5% is being utilized. This study was aimed at evaluating the irrigation potential of some of the key sub-basins in the ZRB, against crop water requirements (CWR). The study applied CropWat 8.0 program by FAO with climate and rainfall data files obtained from CLIMWAT, the FAO's climate database. Three stations in each of four riparian countries were selected namely: Makhanga, Ngabu and Thyolo in Malawi; Mutarara, Caia and Mopeta in Mozambique; Kasempa, Kwekwe and Kaoma in Zambia; and Gweru, Kabwe, and Maranella in Zimbabwe. Major crops considered were maize, rice, wheat and sugarcane. Based on the modelled results, CWR for the same crop are different, largely influenced by the climatic input. The study found that although there are eight riparian countries in the Zambezi River Basin, their potential contribution in terms of irrigated agriculture is different; with Mozambique, Zambia, Zimbabwe and Malawi being among the countries with a significantly large potential for irrigation.

Keywords: Irrigation potential, Crop water requirements, Cropwat, Climwat, Zambezi River Basin.

Disclaimer

The views expressed in this report are those of the researchers at the University of Malawi's Natural Resources and Environment Centre (NAREC).

Contents

Acknowledgements

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Abbreviations and Acronyms

ACE Water 2:	African Centres of Excellence Water 2 Project
ANG:	Angola
BOT:	Botswana
CA:	Conservation Agriculture
CAH:	Cereal Area Harvested
CT:	Chinyanja Triangle
CWR	Crop Water Requirements
EC:	European Commission
EU:	European Union
ET_O	Evapotranspiration
FAO:	Food and Agriculture Organisation
GDP:	Gross Domestic Product
IR	Irrigation Requirements
SWD	Specific Water Demands
IWMI:	International Water Management Institute
MAL:	Malawi
MOZ:`	Mozambique
NAM:	Namibia
NAREC:	Natural Resources and Environment Centre
NEPAD:	New Partnership for Africa's Development
RUE:	Radiation Use Efficiency
SADC:	Southern African Development Community
SANWATCE:	Southern Africa Network of Water Centres of Excellence
TAN:	Tanzania
UNIMA:	University of Malawi
WUA:	Water Use Efficiency
WB:	World Bank
ZACPRO:	Zambezi Action Plan Project
ZAM:	Zambia
ZAMCOM:	Zambezi Watercourse Commission
ZAMWIS;	Zambezi Water Resources Information System
ZIM:	Zimbabwe.
ZRB:	Zambezi River Basin

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1.0. Introduction

Water is ban economic good and a limited resource (Hoekstra & Hung, 2005); as such, its consumptive use has to be within adequate limits for its sustainability. Irrigation water is among the consumptive water uses that require critical assessments epically in critical basins. Water resources in key river basins of sub-Saharan Africa are expected to be highly stressed by 2020, as they have to cope with increasing irrigation demands for food production (FAO, 1995). The Zambezi River Basin (ZRB) in Southern Africa (Fig 1) and the 8 riparian countries therein (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe), will not be spared, as its population rapidly grows amidst considerable water and related socioeconomic infrastructural developments. The total catchment area of the ZRB is 1.39 million km² (139 million hectares) and the proportionate areas for the countries that contribute to the Zambezi River Basin and the average annual rainfall for each sub basin are as shown in Table 1. The biggest proportion of the basin lies within Zambia (42.5%), followed by Angola (17.4%), Zimbabwe (15.8%), Mozambique (12%), Malawi (8%), Tanzania (2.1%), Namibia (1.3%) and Botswana (0.9%) in that sequence.

Table 1: Countries within the Zambezi Basin, their proportional area and rainfall

	Country area (km²)	Area within the basin (km²)	Proportion to the basin (%)	Proportion to the country (%)	Average annual rainfall in the basin area (mm)		
					min.	max.	mean
Angola	1,246,700	235,423	17.4	18.9	550	1475	1050
Namibia	824,900	17,426	1.3	2.1	545	690	630
Botswana	581,730	12,401	0.9	2.1	555	665	595
Zimbabwe	390,760	213,036	15.8	54.5	525	1590	710
Zambia	752,610	574,875	42.5	76.4	600	1435	955
Tanzania	945,090	27,840	2.1	2.9	1015	1785	1240
Malawi	118,480	108,360	8	91.5	745	2220	990
Mozambique	801,590	162,004	12	20.2	555	1790	905
Zambezi basin		1,351,365	100		535	2220	930

The ZRB has an estimated total irrigation potential of over 30 thousand km² (3 million hectares) according to (Tilmant et al., 2010), of which only 5% was already developed as of 2010. The same authors argue that hydropower is the ZRBs major commercial use of water, with an installed total capacity of 4,500 MW mainly in Zambia, Zimbabwe and Mozambique. Although hydropower is not a consumptive water use, the reservoirs constructed have altered natural downstream water flows, thereby affecting aquatic life. In addition, these reservoirs increase the area exposed to open water evaporation.

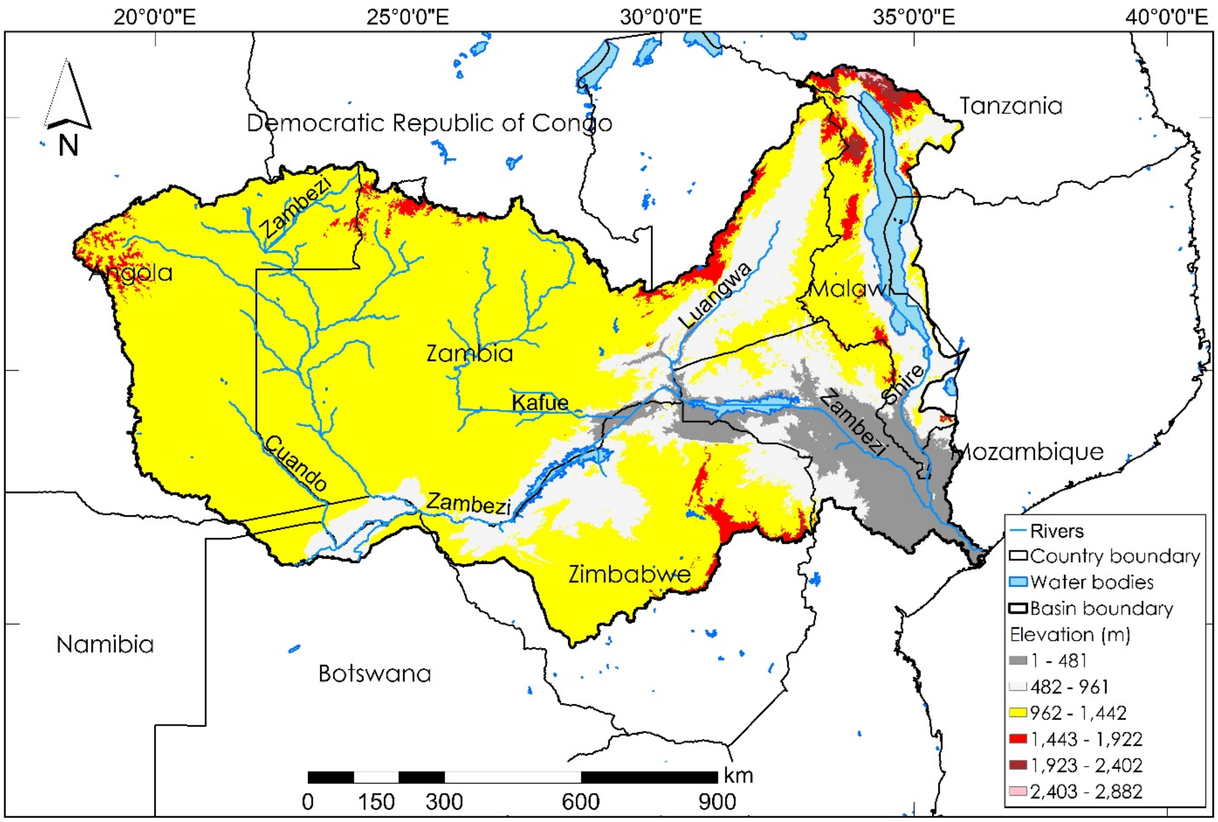

Figure 1. Map of the Zambezi basin and Major Rivers

1.1 Study Aims and Deliverable

This study presents findings on the assessment of the irrigation potential of the Zambezi River Basin (ZRB) in Southern Africa. The study analyzed various kinds of data to assess crops water demand, productivity and potential impact of irrigation expansion and scenario-based management practices. The deliverable is a report on irrigation potential of the ZRB.

2.0 Study Approach

Irrigation water has to be applied just enough to fill-up the root zone, and replenish the water lost through evapotranspiration and satisfy the specific water demands (SWD). SWD is dependent upon the type and stage of crop, soil type and climatic conditions, which cumulatively define the crop water requirements (CWR). Crop water requirements (m^3 ha^{-1}) can be calculated from the accumulated crop evapotranspiration (ETc) in mm day^{-1} over its complete growing period (Allen et al., 1998). This report applied CWR scenarios for the Zambezi River Basin using the CropWat 8.0 program by FAO with climate and rainfall data files obtained from CLIMWAT.

CropWat program employs the FAO Penman-Monteith method (FAO 56 PM; Allen et al., 1998) for the calculation of crop water requirement and irrigation demand. The method is given as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_o is the reference evapotranspiration (mm day^{-1}), in this case the daily crop water requirement; R_n is the net radiation at the crop surface ($MJm^{-2}day^{-1}$), and Allen et al (1998) outline the estimation procedures; G is the soil heat-flux density ($MJm^{-2}day^{-1}$), normally assumed zero for daily calculations; T is the mean daily air temperature (°C) at a height of 2 m; u_2 is the wind speed at a height of 2 m (ms^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure (kPa), which is based on relative humidity measurements; $(e_s - e_a)$ is the saturation vapor pressure deficit (VPD) (kPa); Δ is the slope of the vapor pressure curve (kPa °C−1); and γ is the psychrometric constant (kPa $°C^{-1}$). Allen et al. (1990) presents procedures for the estimation of the rest of the variables.

The CropWat program also permits the development of irrigation schedules for different crops under varying cropping patterns. In addition, the program can be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions (Abdulla et al., 2015). The development of irrigation schedules is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. The scenarios in this study were evaluated for the major sub basins of the Zambezi Basin. The Zambezi river basin is the fourth-largest in Africa, after the Congo/Zaire, Nile and Niger basins (Tilmant et al., 2010). The river originates from the Kalene hills in north-western Zambia and flows to the Indian Ocean through Angola, Namibia, Botswana, Zimbabwe and Mozambique.

3.0 Irrigation Potential

The Zambezi River Basin has significant potential for both energy and agricultural production that is not being fully exploited (Spalding-fecher et al., 2014). It is not the entire potential irrigable area within the basin however that is fully utilised for such, largely due to the rugged and very steep terrain in many parts. The World Bank (2010) estimates on the total irrigation potential (ha) and area under current irrigation utilisation (ha) is as shown in Table 2.

Table 2: Irrigation potential and area under irrigation within the basin

Country	Irrigation potential (ha)	Area under irrigation (ha)
Angola	700000	6125
Namibia	11000	140
Botswana	1080	0
Zimbabwe	165400	108717
Zambia	422000	74661
Tanzania	100000	23140
Malawi	160900	37820
Mozambique	1700000	20000
Sum for the countries	3260380	270603

Source: (World Bank, 2010)

3.1 Major crops grown under irrigated agriculture

Based on a number of reports, the crops grown under irrigation vary from country to country within the basin. In general, the major crops grown under irrigated agriculture in the basin include sugarcane, wheat, rice, maize, cotton, soybean (Davis, 2003). For each of the eight countries in the basin, there are predominant crops that are grown under irrigated agriculture; and for purposes of this report a total of 7 crops have been retained for their relative importance in the subparts. The crop water requirement (CWR) simulations in this report are based on these seven crops grown in the core countries of the basin. Table 3 shows the major crops grown under irrigated agriculture for each of the eight countries. The asterisks indicate the crop grown and level of importance in a particular country. In terms of irrigation area within the Zambezi Basin, four countries (namely Malawi, Mozambique, Zambia and Zimbabwe) have the largest current and planned share of agricultural land and hence the major crops grown in these countries will be of particular interest.

Table 3: Major crops grown in each country within the Zambezi Basin

Country	Maize	Rice	Soybean	Wheat	Sugarcane	Cotton	Fruits
Angola		***			***		
Botswana	*					*	
Malawi	***	***			****	**	
Mozambique					****		
Namibia	**			**		*	*
Tanzania	***	*****			***	***	***
Zambia	***	***		***	***		**
Zimbabwe	***		**	****	****	**	**

Source: Davis (2003)

3.2 Crop water requirements (CWR)

Table 4 is a summary of weather stations that were considered for each country in the analyses. These stations were selected considering their proximity to the irrigable area within the basin. The climatic data from these stations are used for the calculation of crop water requirements. Some of the parameters used include temperature, humidity, wind speed and solar radiation.

Table 4: Weather stations considered for this report

	Malawi	Mozambique	Zambia	Zimbabwe
Station	Makanga	Mutarara	Kasempa	Kwekwe
	Ngabu	Caia	Kaoma	Gweru
	Thyolo	Mopeta	Kabwe	Maranellas

3.2.1 CWR for Sugarcane within Malawi (Shire sub basin)

Figure 2 shows the computed CWR (mm/dec) and irrigation requirements (mm/dec) for Sugarcane, modelled using climatic data from Makanga and Ngabu stations. Modelled results show ETc as high as 8.16mm/day and 83.9 mm/dec as shown in the figure 2. In terms of irrigation requirements, the most demand will be in October assuming the crop is planted in January. From the graph, IR between January and February shows a value of zero (0), which could be compensated by the effective rainfall during that period.

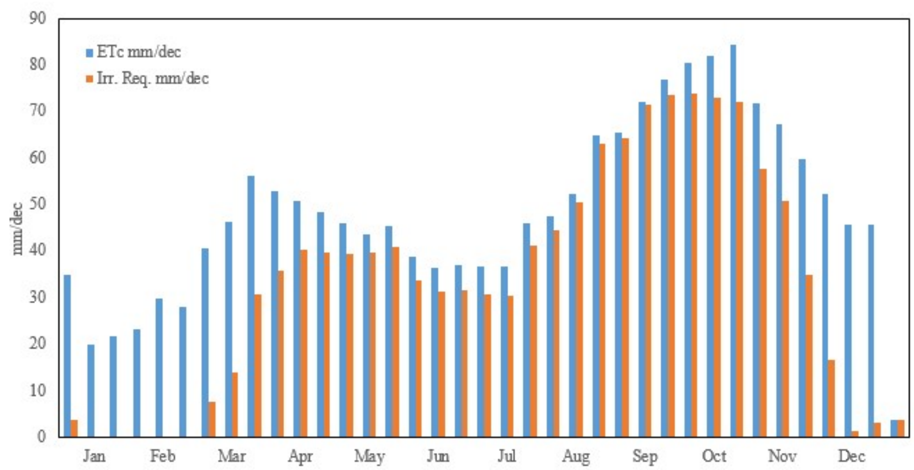

Figure 2: The estimated ET_c (mm/dec) and IR (mm/dec) for sugarcane in Malawi

Based on the irrigation requirements, Figure 3 shows the estimated required irrigation flow rate in litres/second/hectare. As shown, a maximum flow of 1.1 (*l/s/ha*) will be required during the most critical period. Assuming a worst case scenario that the entire 37,820 ha under irrigation at the same time, it implies an abstraction of 41.602 m^3/s of water from the water source.

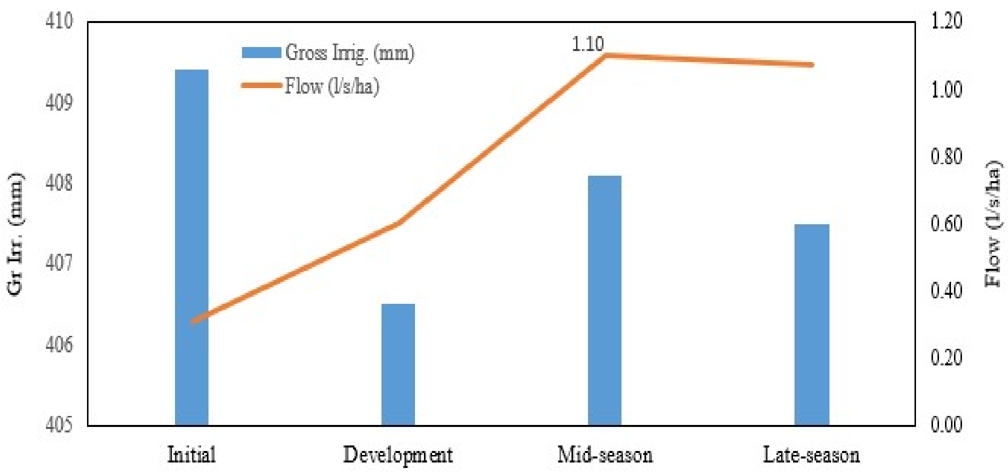

Figure 3: The gross IR and estimated flow required per hectare for sugarcane in lower Shire

3.2.2 Crop water requirements for maize (Malawi – Shire sub basin)

Assuming maize is planted in April which is the period after the rainy season, Figure 4 shows the ETc and irrigation requirements for the crop within the lower Shire River sub-basin. Compared to sugarcane, the CWR for maize are quite low. The estimated highest required flow rate per hectare for maize is calculated to be 0.32l/s/ha. At critical stage therefore, about 12.14 m^3/s would be required (assuming the entire area is irrigated at the same time, and under a monocrop). The required flow is about quarter of what would be required for sugarcane.

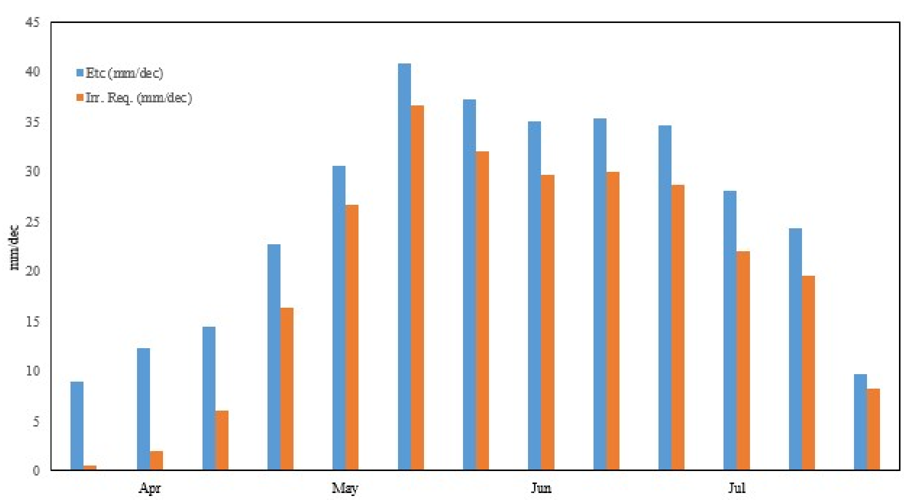

Figure 4: The estimated ETc (mm/dec) and IR (mm/dec) for maize in Malawi

3.2.3 Crop water requirements for rice (Malawi – Shire sub basin)

Figure 5 below shows the estimated crop water requirements for rice in the lower Shire sub-basin of the Zambezi. As shown in the figure below, rice would require irrigation water about two folds and four folds of what would be required for sugarcane and maize, respectively. It is estimated therefore that at the most critical stage, about 80 m^3/s would be required to irrigate the same area of 37,820 ha.

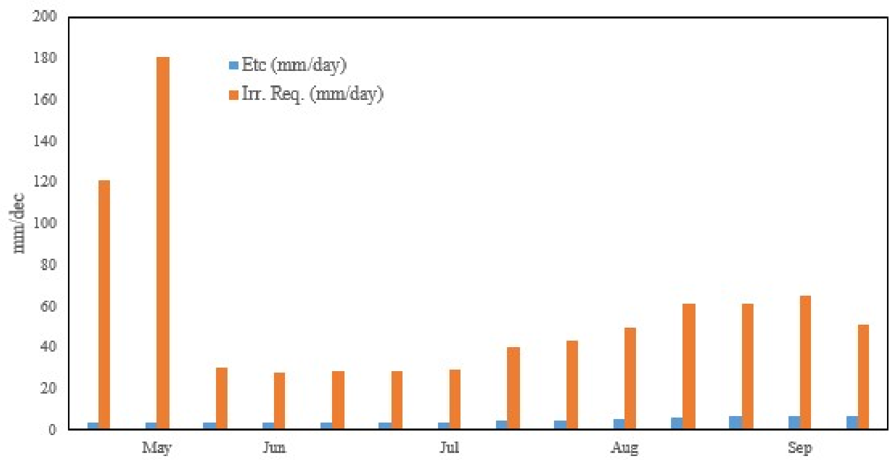

Figure 5: The estimated ETc (mm/dec) and IR (mm/dec) for rice in Malawi

3.2.4 CWR for sugarcane within the Mozambique portion of Zambezi Basin

Since sugarcane is the major crop grown under irrigation in the Mozambique portion of the basin (Table 3), the CWR for that portion are estimated only for sugarcane. The Mutarara, Caia and Mopeta weather stations were used for the estimations. Figure 5 shows the flow rate of irrigation water and the gross irrigation water that would be required. It is shown in the figure 5 that at the most critical stage, 0.99 *l/s/ha* would be required. Assuming that the entire 74,661 ha that is under irrigation is irrigated at the same time, it implies that 73.91 m^3/s will have to be abstracted.

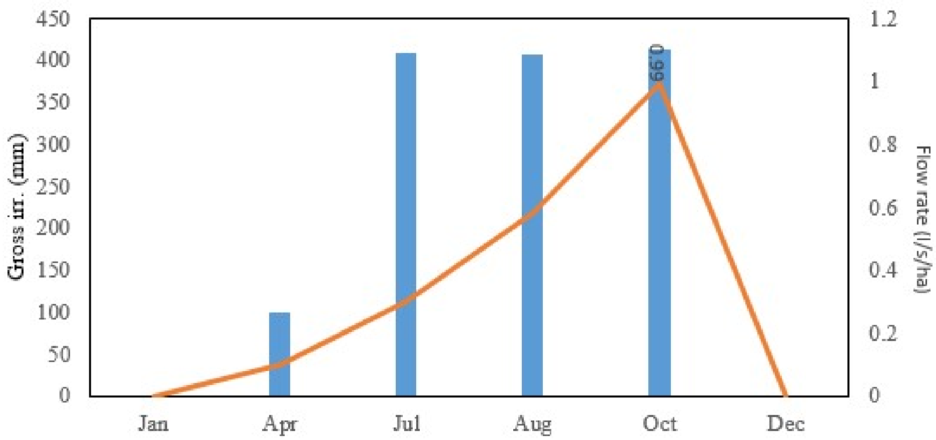

Figure 6: The gross IR and flow rates per hectare required for sugarcane (Mozambique)

3.2.5 CWR for wheat within the Zambian portion of the basin

Climatic data for the Zambian portion of the basin used in these analyses were obtained from the Kasempa, Kaoma and Kabwe weather stations. Maize and wheat were the major crops estimated for their CWR on the Zambian portion. Figures 7 and 8 show the modelled crop water requirements for maize and wheat for the Zambia portion of the basin.

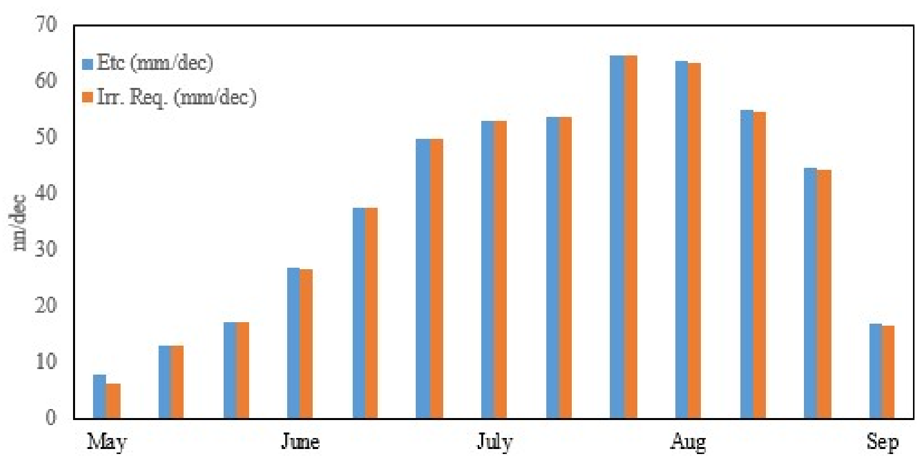

Figure 7: The estimated ETc (mm/dec) and IR (mm/dec) for maize in Zambia

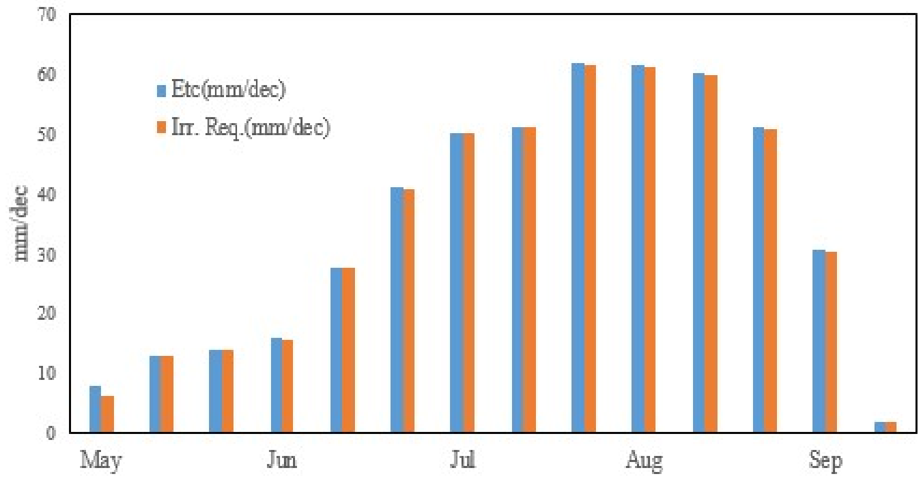

Figure 8: The estimated ETc (mm/dec) and IR (mm/dec) for wheat in Zambia

From Figures 7 and 8, it is shown that the CWR for maize and wheat respectively follow a similar pattern assuming planting is done in May. The critical irrigation requirements in terms of flow rate for the two crops are also quite similar; with maize demanding 1.0 *l/s/ha* while wheat would require 1.02 *l/s/ha*. Assuming the entire 74,661 ha is under wheat or maize as standalone crops, it would require approximately 75m^3/s flow of abstracted water during the critical period.

3.2.6 CWR for sugarcane within the Zimbabwe portion of the basin

Assuming the sugarcane crop is planted in January within the Zimbabwe portion of the Zambezi Basin, the Figures 9 and 10 below present the CWR and required flows to meet the demands. As shown in Figure 10, at the most critical stage of the sugarcane demand abstraction of 1.25*l/s/ha* if the entire area is under sugarcane alone, and is irrigated at the same time. At that flow rate, 135.9m^3/s would have to be abstracted to meet the demands.

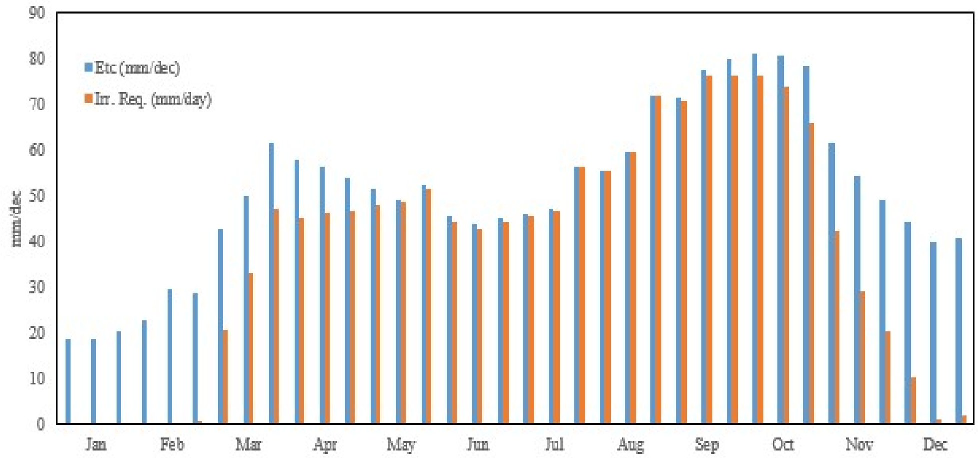

Figure 9: The estimated ETc (mm/dec) and IR (mm/dec) for sugarcane in Zimbabwe

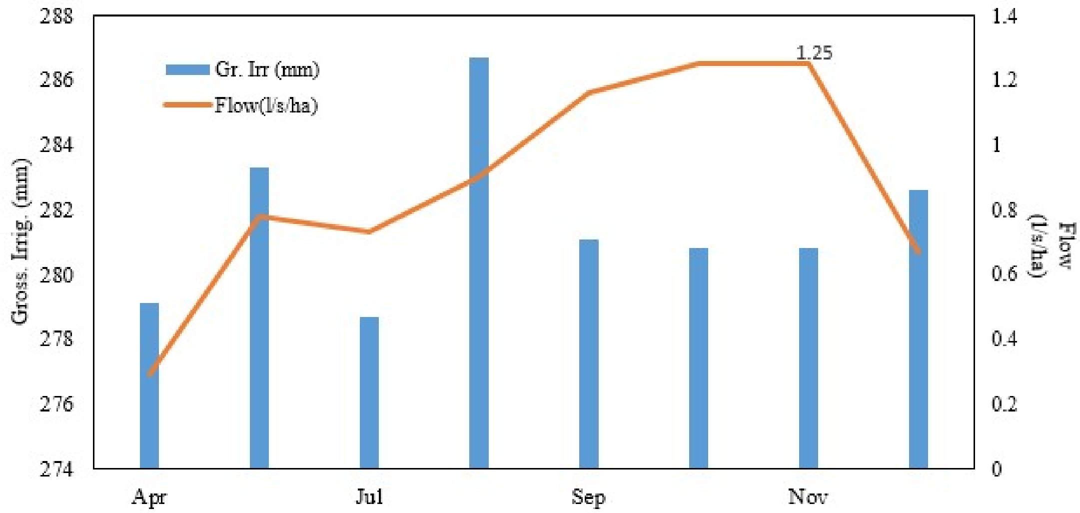

Figure 10: The gross IR and flow rates per hectare required for sugarcane in Zimbabwe

4.0 Conclusion

Based on the modelled results, CWR for the same crop are different, largely influenced by the climatic input. The report also shows that although eight countries form part of the Zambezi River Basin, their potential contribution in terms of irrigated agriculture is different; with Mozambique, Zambia, Zimbabwe and Malawi being among the countries with a significantly large potential for irrigation.

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Appendices

Appendix 1: Average climatic data and ETo for Makanga Weather Station

Monthly ETo Penman-Monteith - C:\Program Files (x86)\CLIMWAT 2.0 for C...

Country: Location 17 | Station: MAKANGA

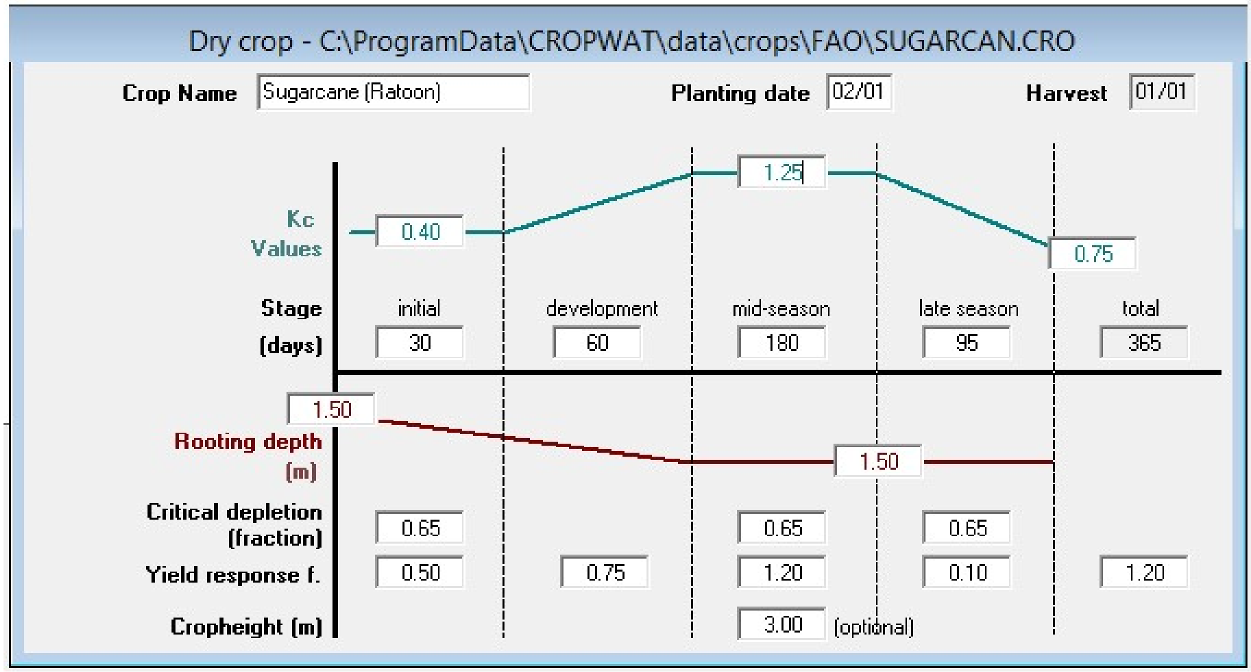
Altitude: 58 m. | Latitude: 16.51 °S | Longitude: 35.15 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	22.9	33.2	78	121	7.4	22.1	4.99
February	22.7	33.3	79	104	7.4	21.7	4.83
March	22.1	32.5	78	112	7.7	21.0	4.61
April	20.3	31.0	76	121	8.0	19.3	4.11
May	17.0	29.9	73	112	8.2	17.3	3.52
June	14.3	27.9	72	112	7.5	15.3	2.97
July	14.3	27.5	70	130	7.4	15.7	3.07
August	15.7	30.3	62	164	8.7	19.2	4.24
September	18.8	33.6	54	216	8.9	21.9	5.83
October	21.5	35.7	51	251	9.1	23.9	7.05
November	22.8	35.8	59	225	8.8	24.1	6.71
December	23.3	34.2	71	156	7.5	22.2	5.45
Average	**19.6**	**32.1**	**69**	**152**	**8.1**	**20.3**	**4.78**

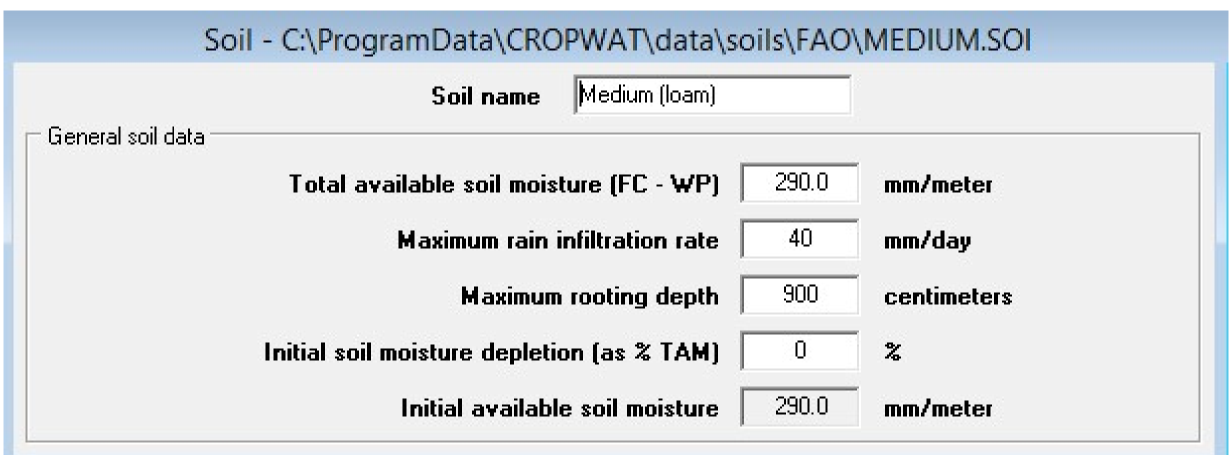
Appendix 2: Average monthly rainfall and effective rainfall for Makanga Station

	Rain	Eff rain
	mm	mm
January	157.4	117.8
February	127.4	101.4
March	110.5	91.0
April	38.0	35.7
May	14.8	14.4
June	16.5	16.1
July	17.3	16.8
August	6.6	6.5
September	5.0	5.0
October	28.9	27.6
November	61.2	55.2
December	167.0	122.4
Total	**750.6**	**609.8**

Appendix 3: Kc values and stages of growth for sugarcane



Appendix 4: Soils data input



Appendix 5: Crop Irrigation Schedule for sugarcane (lower Shire – Malawi)

Crop irrigation schedule

ETo station	MAKANGA	**Crop**	Sugarcane (Ratoon)	**Planting date**	02/01	**Yield red.**	
Rain station	MAKANGA	**Soil**	Medium (loam)	**Harvest date**	01/01		0.0 %

Table format
- (•) **Irrigation schedule**
- ( ) **Daily soil moisture balance**

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

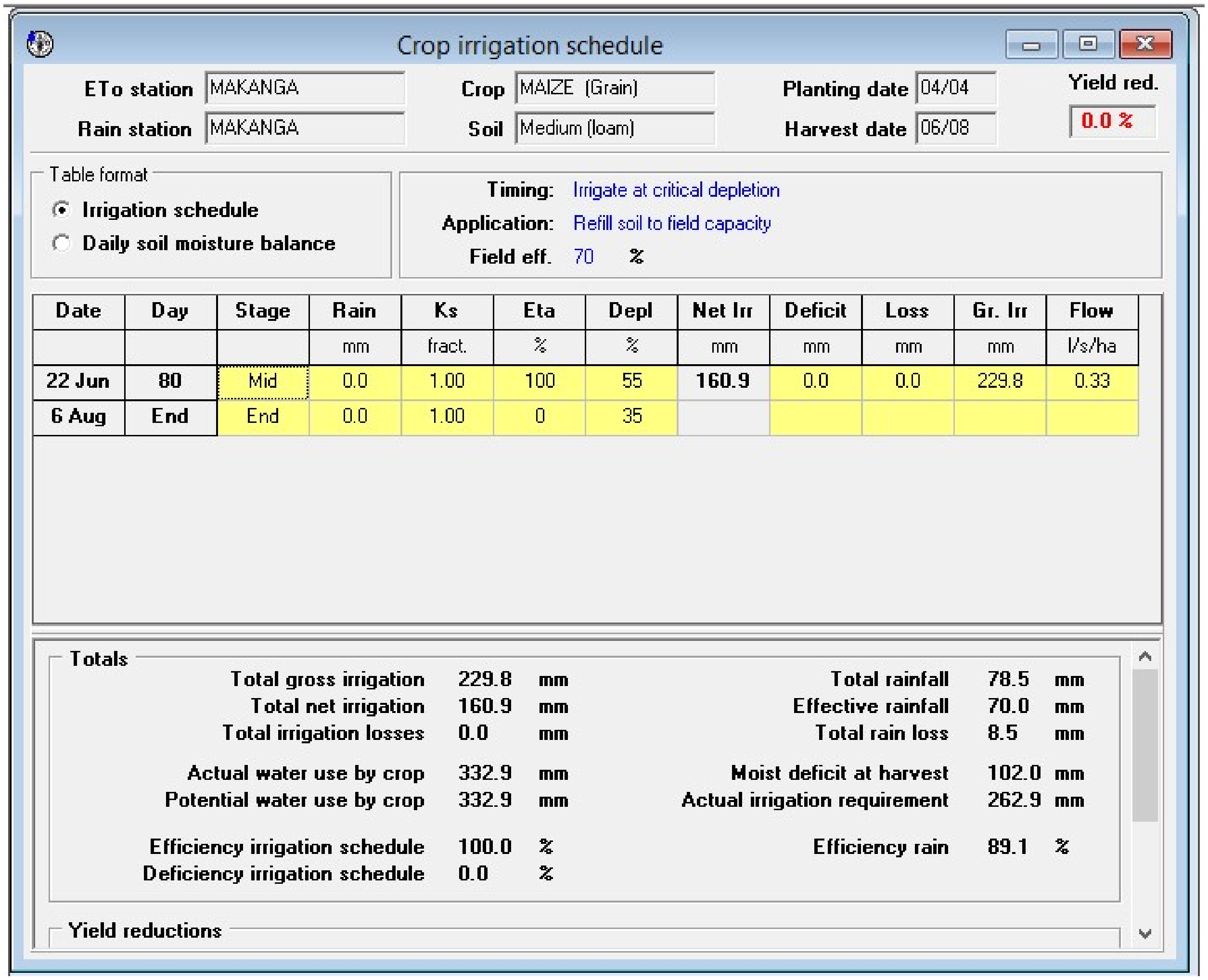
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
1 Jun	151	Mid	0.0	1.00	100	66	286.6	0.0	0.0	409.4	0.31
19 Aug	230	Mid	0.0	1.00	100	65	284.5	0.0	0.0	406.5	0.60
1 Oct	273	End	0.0	1.00	100	66	285.6	0.0	0.0	408.1	1.10
14 Nov	317	End	0.0	1.00	100	66	285.2	0.0	0.0	407.5	1.07
1 Jan	End	End	0.0	1.00	0	9					

Totals

Total gross irrigation	1631.4 mm	Total rainfall	750.8 mm
Total net irrigation	1142.0 mm	Effective rainfall	607.9 mm
Total irrigation losses	0.0 mm	Total rain loss	143.0 mm
Actual water use by crop	1788.3 mm	Moist deficit at harvest	38.5 mm
Potential water use by crop	1788.3 mm	Actual irrigation requirement	1180.5mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	81.0 %
Deficiency irrigation schedule	0.0 %		

Yield reductions

Appendix 6: Crop Irrigation Schedule for maize (lower Shire – Malawi)



Crop irrigation schedule

ETo station MAKANGA
Rain station MAKANGA
Crop MAIZE (Grain)
Soil Medium (loam)
Planting date 04/04
Harvest date 06/08
Yield red. 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
22 Jun	80	Mid	0.0	1.00	100	55	160.9	0.0	0.0	229.8	0.33
6 Aug	End	End	0.0	1.00	0	35					

Totals

Total gross irrigation	229.8	mm	Total rainfall	78.5	mm
Total net irrigation	160.9	mm	Effective rainfall	70.0	mm
Total irrigation losses	0.0	mm	Total rain loss	8.5	mm
Actual water use by crop	332.9	mm	Moist deficit at harvest	102.0	mm
Potential water use by crop	332.9	mm	Actual irrigation requirement	262.9	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	89.1	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Appendix 7: **Crop water requirements (lower Shire – Malawi)**

Crop Water Requirements

ETo station MAKANGA **Crop** MAIZE (Grain)

Rain station MAKANGA **Planting date** 04/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.30	1.28	9.0	11.9	0.5
Apr	2	Init	0.30	1.23	12.3	10.3	2.0
Apr	3	Deve	0.37	1.45	14.5	8.5	6.0
May	1	Deve	0.61	2.28	22.8	6.5	16.4
May	2	Deve	0.87	3.05	30.5	3.8	26.7
May	3	Mid	1.12	3.72	40.9	4.3	36.7
Jun	1	Mid	1.18	3.72	37.2	5.2	32.0
Jun	2	Mid	1.18	3.50	35.0	5.4	29.7
Jun	3	Mid	1.18	3.54	35.4	5.4	30.0
Jul	1	Late	1.16	3.46	34.6	5.9	28.7
Jul	2	Late	0.95	2.81	28.1	6.1	22.0
Jul	3	Late	0.65	2.22	24.4	4.8	19.6
Aug	1	Late	0.42	1.61	9.7	1.8	8.2
					334.5	**79.7**	**258.4**

Appendix 9: **Crop Irrigation Schedule for rice (Lower Shire – Malawi)**

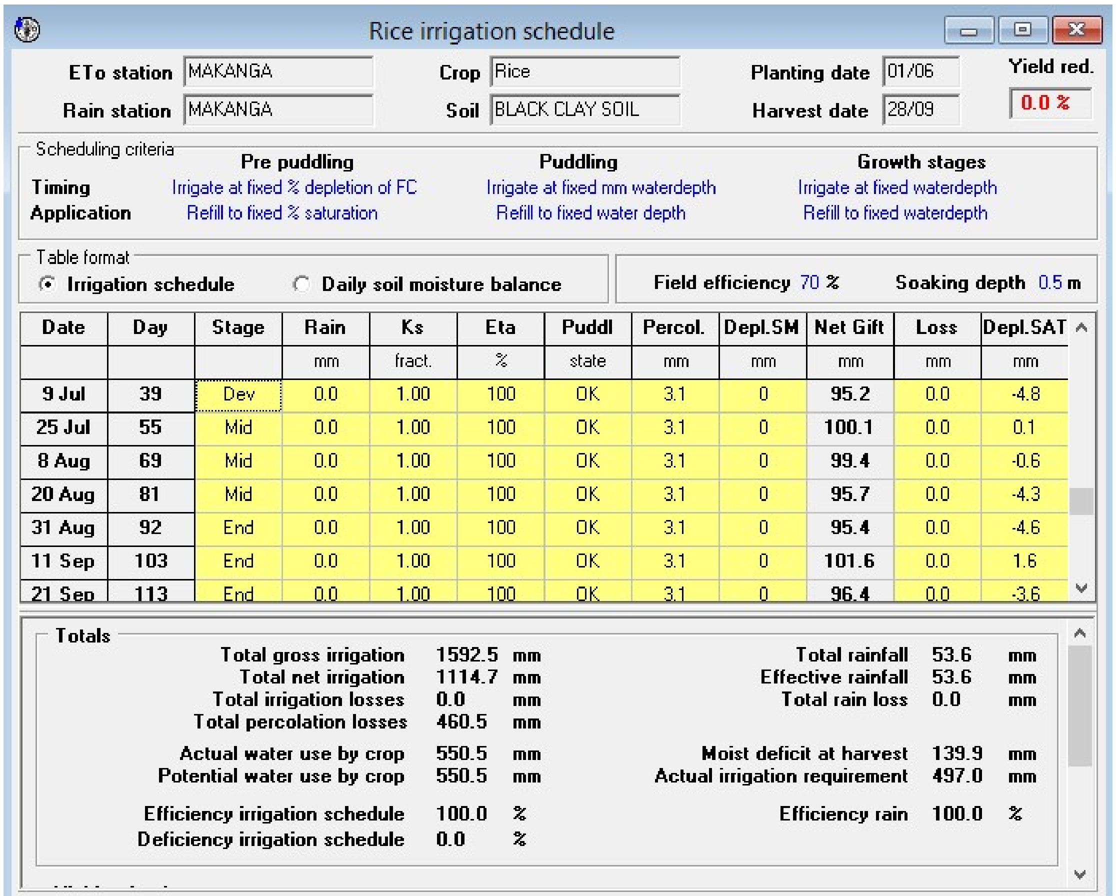
Crop Water Requirements

ETo station MAKANGA **Crop** Rice

Rain station MAKANGA **Planting date** 01/06

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	LandPrep	1.05	3.69	33.2	3.4	120.8
May	3	LandPrep	1.05	3.50	38.5	4.3	180.3
Jun	1	Init	1.10	3.46	34.6	5.2	29.5
Jun	2	Init	1.10	3.26	32.6	5.4	27.3
Jun	3	Deve	1.12	3.36	33.6	5.4	28.1
Jul	1	Deve	1.15	3.42	34.2	5.9	28.4
Jul	2	Deve	1.19	3.53	35.3	6.1	29.2
Jul	3	Mid	1.20	4.08	44.9	4.8	40.1
Aug	1	Mid	1.20	4.63	46.3	3.1	43.2
Aug	2	Mid	1.20	5.09	50.9	1.8	49.2
Aug	3	Late	1.20	5.73	63.0	1.7	61.2
Sep	1	Late	1.17	6.20	62.0	1.1	60.9
Sep	2	Late	1.13	6.57	65.7	0.6	65.1
Sep	3	Late	1.09	6.78	54.3	2.7	50.8
					629.0	**51.4**	**814.0**

Appendix 10: Rice Irrigation Schedule for lower Shire - Malawi



Rice irrigation schedule

ETo station	MAKANGA	Crop	Rice	Planting date	01/06
Rain station	MAKANGA	Soil	BLACK CLAY SOIL	Harvest date	28/09

Yield red. 0.0 %

Scheduling criteria

	Pre puddling	Puddling	Growth stages
Timing	Irrigate at fixed % depletion of FC	Irrigate at fixed mm waterdepth	Irrigate at fixed waterdepth
Application	Refill to fixed % saturation	Refill to fixed water depth	Refill to fixed waterdepth

Table format: (•) Irrigation schedule ( ) Daily soil moisture balance

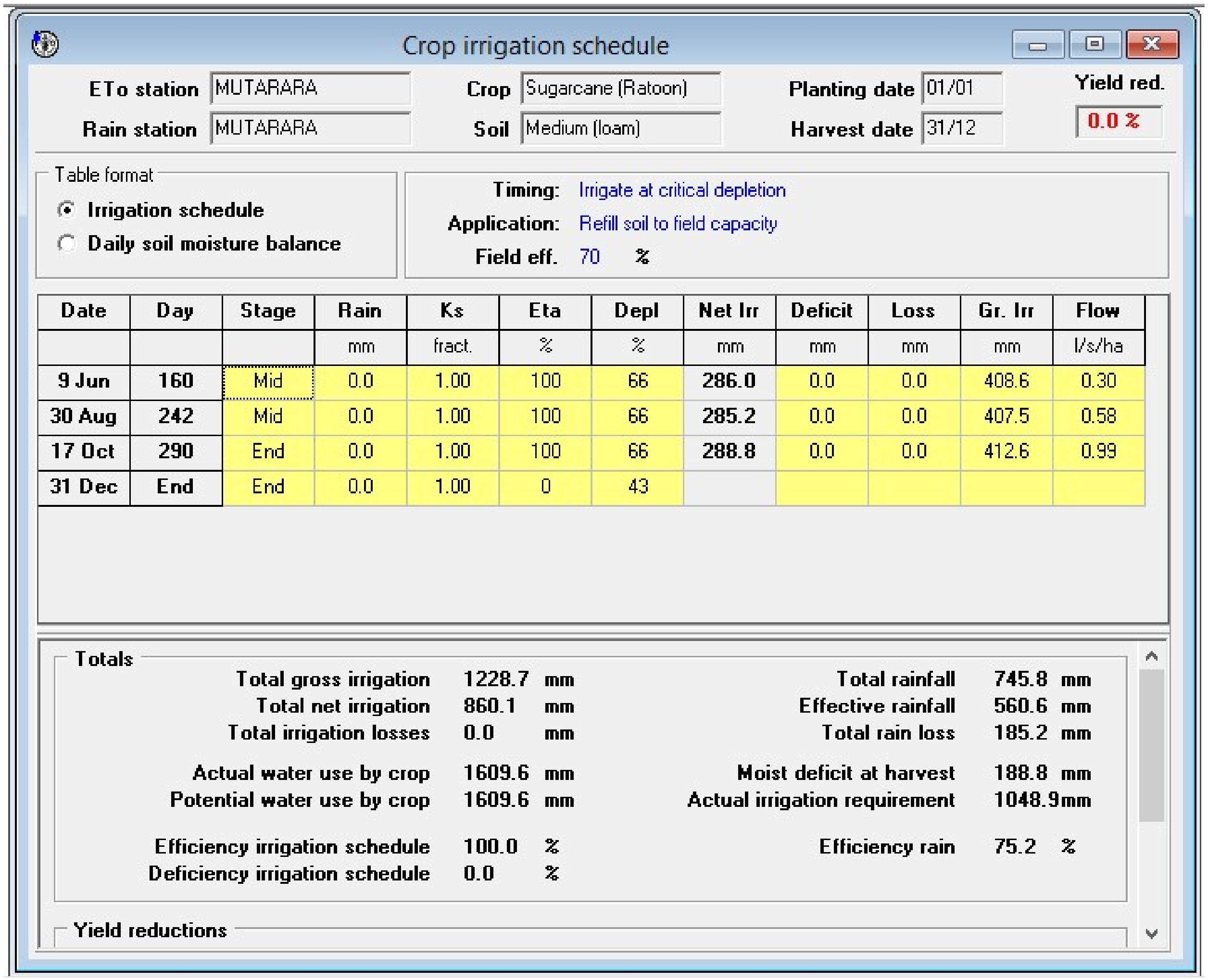
Field efficiency 70 % Soaking depth 0.5 m

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
9 Jul	39	Dev	0.0	1.00	100	OK	3.1	0	95.2	0.0	-4.8
25 Jul	55	Mid	0.0	1.00	100	OK	3.1	0	100.1	0.0	0.1
8 Aug	69	Mid	0.0	1.00	100	OK	3.1	0	99.4	0.0	-0.6
20 Aug	81	Mid	0.0	1.00	100	OK	3.1	0	95.7	0.0	-4.3
31 Aug	92	End	0.0	1.00	100	OK	3.1	0	95.4	0.0	-4.6
11 Sep	103	End	0.0	1.00	100	OK	3.1	0	101.6	0.0	1.6
21 Sep	113	End	0.0	1.00	100	OK	3.1	0	96.4	0.0	-3.6

Totals

Total gross irrigation	1592.5	mm	Total rainfall	53.6	mm
Total net irrigation	1114.7	mm	Effective rainfall	53.6	mm
Total irrigation losses	0.0	mm	Total rain loss	0.0	mm
Total percolation losses	460.5	mm			
Actual water use by crop	550.5	mm	Moist deficit at harvest	139.9	mm
Potential water use by crop	550.5	mm	Actual irrigation requirement	497.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	100.0	%
Deficiency irrigation schedule	0.0	%			

Appendix 11: Crop irrigation schedule for sugarcane - Mozambique



Crop irrigation schedule

ETo station: MUTARARA | Crop: Sugarcane (Ratoon) | Planting date: 01/01 | Yield red.: 0.0 %

Rain station: MUTARARA | Soil: Medium (loam) | Harvest date: 31/12

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion

Application: Refill soil to field capacity

Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
9 Jun	160	Mid	0.0	1.00	100	66	286.0	0.0	0.0	408.6	0.30
30 Aug	242	Mid	0.0	1.00	100	66	285.2	0.0	0.0	407.5	0.58
17 Oct	290	End	0.0	1.00	100	66	288.8	0.0	0.0	412.6	0.99
31 Dec	End	End	0.0	1.00	0	43					

Totals

Total gross irrigation	1228.7 mm	Total rainfall	745.8 mm
Total net irrigation	860.1 mm	Effective rainfall	560.6 mm
Total irrigation losses	0.0 mm	Total rain loss	185.2 mm
Actual water use by crop	1609.6 mm	Moist deficit at harvest	188.8 mm
Potential water use by crop	1609.6 mm	Actual irrigation requirement	1048.9mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	75.2 %
Deficiency irrigation schedule	0.0 %		

Yield reductions

Appendix 12: **Climatic data for Mutarara Weather Station (Mozambique)**

Monthly ETo Penman-Monteith - C:\Program Files (x86)\CLIMWAT 2.0 for C...

Country: Location 94 | Station: MUTARARA

Altitude: 88 m. | Latitude: 17.38 °S | Longitude: 35.05 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	22.5	33.8	73	147	6.4	20.5	5.00
February	22.6	33.7	77	130	6.1	19.7	4.65
March	21.7	32.7	73	130	6.4	18.9	4.46
April	20.0	31.9	75	138	6.5	17.1	3.95
May	17.0	30.1	73	130	5.5	13.7	3.18
June	14.4	28.1	75	130	5.6	12.9	2.74
July	14.1	28.2	75	138	5.5	13.2	2.81
August	15.5	30.3	71	173	6.3	15.9	3.66
September	18.1	33.0	66	199	6.6	18.4	4.75
October	20.7	36.1	61	225	7.3	21.1	6.04
November	22.3	36.2	65	225	6.6	20.6	5.94
December	22.9	34.9	73	173	5.7	19.5	5.09
Average	**19.3**	**32.4**	**71**	**161**	**6.2**	**17.6**	**4.36**

Appendix 13: **Rainfall data for Mutarara Weather Station (Mozambique)**

Monthly rain - C:\Program Files (x86)\CLIMWAT 2.0 for CROPWAT ...

Station: MUTARARA | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	157.0	117.6
February	150.0	114.0
March	119.0	96.3
April	33.0	31.3
May	22.0	21.2
June	12.0	11.8
July	20.0	19.4
August	9.0	8.9
September	11.0	10.8
October	9.0	8.9
November	81.0	70.5
December	123.0	98.8
Total	**746.0**	**609.4**

Appendix 14: **Crop irrigation schedule for maize in Zambia**

Crop irrigation schedule

ETo station: KASEMPA | Crop: MAIZE (Grain) | Planting date: 05/05 | Yield red.: 0.0 %

Rain station: KASEMPA | Soil: BLACK CLAY SOIL | Harvest date: 06/09

Table format
- Irrigation schedule
- Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
8 May	4	Init	0.0	1.00	100	55	38.7	0.0	0.0	55.2	1.60
4 Jun	31	Dev	0.0	1.00	100	57	78.8	0.0	0.0	112.5	0.48
25 Jun	52	Dev	0.0	1.00	100	55	106.0	0.0	0.0	151.4	0.83
16 Jul	73	Mid	0.0	1.00	100	56	112.8	0.0	0.0	161.1	0.89
4 Aug	92	Mid	0.0	1.00	100	56	111.6	0.0	0.0	159.4	0.97
6 Sep	End	End	0.0	1.00	0	76					

Potential water use by crop 502.6 mm | Actual irrigation requirement 499.0 mm

Efficiency irrigation schedule 100.0 % | Efficiency rain 100.0 %

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	0.40	0.40	1.30	0.50	1.25	
Yield reduction	0.0	0.0	0.0	0.0		%

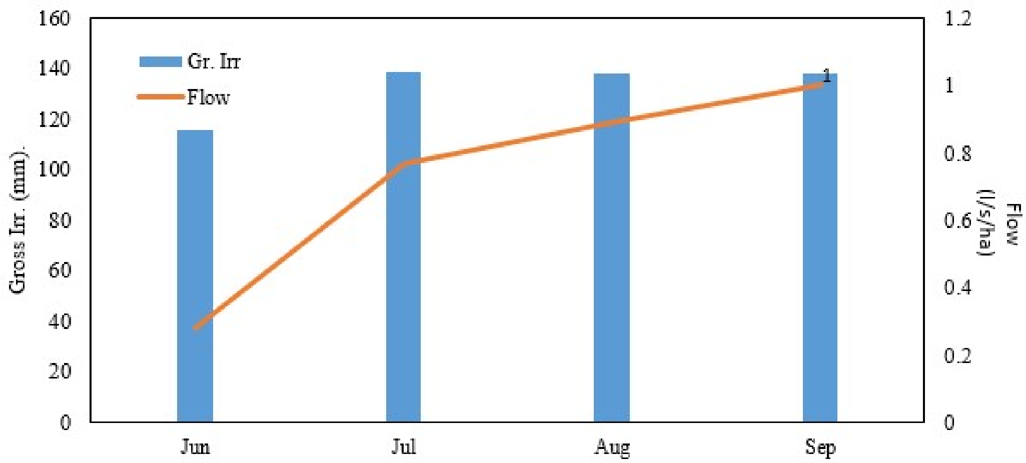
Appendix 15: **Climatic data for Kwekwe Weather Station - Zimbabwe**

Monthly ETo Penman-Monteith - C:\Program Files (x86)\CLIMWAT 2.0 for C...

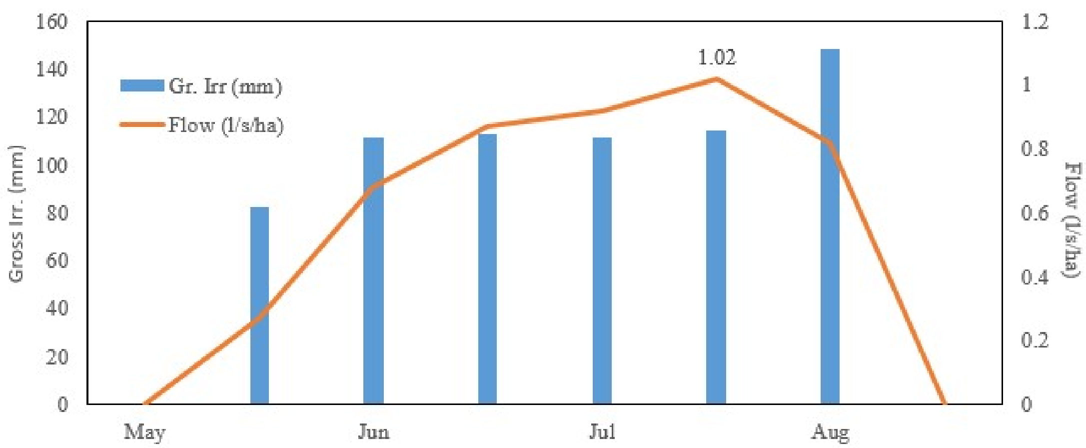
Country: Location 32 | Station: KWEKWE

Altitude: 1215 m. | Latitude: 18.93 °S | Longitude: 29.83 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16.8	28.2	72	156	6.5	20.9	4.59
February	16.4	28.0	72	164	6.7	20.7	4.51
March	14.8	28.2	66	190	7.5	20.5	4.64
April	12.8	27.6	62	190	7.9	18.7	4.29
May	8.6	25.5	57	181	8.5	17.1	3.75
June	6.1	23.1	55	199	8.1	15.4	3.33
July	5.7	23.3	50	207	8.4	16.3	3.59
August	7.8	26.0	44	225	8.8	18.8	4.54
September	11.3	29.4	38	251	8.9	21.5	5.90
October	15.2	31.4	41	251	8.2	22.3	6.47
November	16.4	29.2	57	199	6.5	20.6	5.26
December	16.9	28.2	68	173	6.0	20.0	4.64
Average	12.4	27.3	57	199	7.7	19.4	4.63



Appendix 16:



Appendix 17: Gross irrigation requirement and required inflow for maize - Zambia