Irrigation Requirements for Sugarcane Grown in Central Maui, Hawaii

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Optimal irrigation requirements for sugarcane grown in Central Maui were calculated using a daily water budget computer model for the root zone of each crop. This daily water budget model uses long-term daily weather inputs (rainfall, evapotranspiration) and the physical properties of the specific soil types located in Central Maui, including the areas Hawaiian Commercial and Sugar Company ("HC&S") identifies as the "Waihee-Hopoi" and "Iao-Waikapu" fields.

The water balance equation for the soil column of the crop root zone is defined as follows:

$$\Delta S = P + G + IRR_{net} - Q_{GW+Runoff} - ET_c \qquad (1)$$

where ΔS is the change in soil water storage, P is the rainfall, G is the ground water contribution, IRR_{net} is the net irrigation requirement, $Q_{GW+Runoff}$ is the summation of ground water drainage and surface water runoff, and ET_c is the crop evapotranspiration. The water storage capacity (S) is the available soil water holding capacity (ASWHC) in the crop zone, which is expressed as the product of the ASWHC and the crop root zone depth (z). The ASWHC is the water stored between the field capacity and the permanent wilting point. The field capacity is the amount of water retained by the soil after excess water has drained away 48 to 72 hours following a heavy rain or prolonged irrigation depending on soil type. The permanent wilting point is the minimum soil moisture at which a plant wilts and will no longer be able to take water up from the soil.

As part of its calculations, this model does not allow soil to reach its wilting point; instead, soil is allowed to deplete its available water content up to a given percent, which is defined as the allowable water deficit (AWD). The AWD for sugarcane used in this model was 65% of the

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ASWHC based on established best management practices. After soil water content is depleted to the AWD, the model provides irrigation up to the field capacity.

The gross (daily optimal) irrigation requirement (IRR) was calculated for each crop area as:

$$IRR = \frac{ET_c - R_e - G}{f_i} \qquad (2)$$

where R_e is effective rainfall, which is that portion of the rainfall that is available in the root zone for plant use and is expressed as P minus $Q_{GW+Runoff}$; and f_i is the irrigation efficiency. R_e was calculated using 54 years of historical daily rainfall data (1950-2004). ET_c was calculated as follows:

$$ET_c = K_c \text{ x } ET_o \qquad (3)$$

where K_c is the crop coefficient (see Figure 1), and ET_o is the reference evapotranspiration. Daily ET_o values were generated using historical monthly mean pan evaporation (PE) values published by Ekern and Cheng (1985) as part of the following equation:

$$ET_o = PE \text{ x } K_p \qquad (4)$$

where K_p is the pan coefficient of 0.70 for the appropriate reference crop for sugarcane.

Surface water runoff (Q_{Runoff}) was calculated using the SCS curve number method (USDA-SCS, 1985) using the following equation:

$$Q_{Runoff} = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (5)$$

where P is daily rainfall (in inches), S is potential maximum retention after runoff begins, which is related to the curve number as:

$$S = \frac{1000}{CN} - 10 \qquad (6)$$

CN is the curve number, which is related to the imperviousness of the surface. For impervious surfaces, CN is equal to 100; for natural surfaces, CN is less than 100. CN is determined based on site-specific hydrologic soil groups and land use types -- in this case, sugarcane. The curve numbers 67, 68, 87 and 89 were used for this land use on the four soil hydrologic groups A, B, C and D, respectively. Soil texture and physical characteristics, including the available water capacity of the different soil types, were obtained from the State of Hawaii Soil Survey (USDA, 1972; USDA, 1979).

The water table in this region is deep and not contributing water to the plant root zone.

Root depth, irrigation system type, irrigation system efficiency, and other parameters used in these calculations are provided in Table 1.

Table 1. Parameters for sugarcane for year 1 and year 2.

	Sugarcane Crop	**Year 1**	**Year 2**
Root depth (in inches)		18-36	36
Duration of growth stages (fraction of crop year)	Stage 1	0.21	0.14
	Stage 2	0.29	0.14
	Stage 3	0.25	0.14
	Stage 4	0.25	0.59
Allowable water depletion (fraction of total)		0.65	0.65
Irrigation type		Drip	Drip
Irrigation Efficiency (%)		85	85

The crop coefficient (K_c) is depicted in Figure 1. Each crop year is divided into four growth stages, expressed as fractions of one year. Figure 1 shows the changes of K_c values during sugarcane's two-year crop cycle. Growth stage 1 of year 1, which lasts 0.21 years or 77 days, is the period from planting to plant establishment. Due to the incomplete crop canopies during this stage, the K_c value is 0.4. During days of rainfall exceeding daily potential ET, K_c is set to 1.0. For stage 2 of year 1, the K_c value linearly increases from 0.4 to 1.25, as the crop develops to the point of peak growth. During the peak growth period, which includes stages 3 and 4 of year 1, and stages 1 to 3 of year 2, the K_c is 1.25. This peak growth period continues for 0.41 of the second year. During the 0.59 remaining in the second year, or stage 4 of year 2, K_c decreases linearly to reach 0.75 at the last day of the growing season. The model continues to irrigate the crop even through the last months of its second year. In practice, HC&S states that it does not irrigate its sugarcane for 40 to 60 days before harvest. Thus, the model overestimates the optimal irrigation requirements for HC&S's sugarcane in its Waihee-Hopoi and Iao-Waikapu fields by approximately six percent.

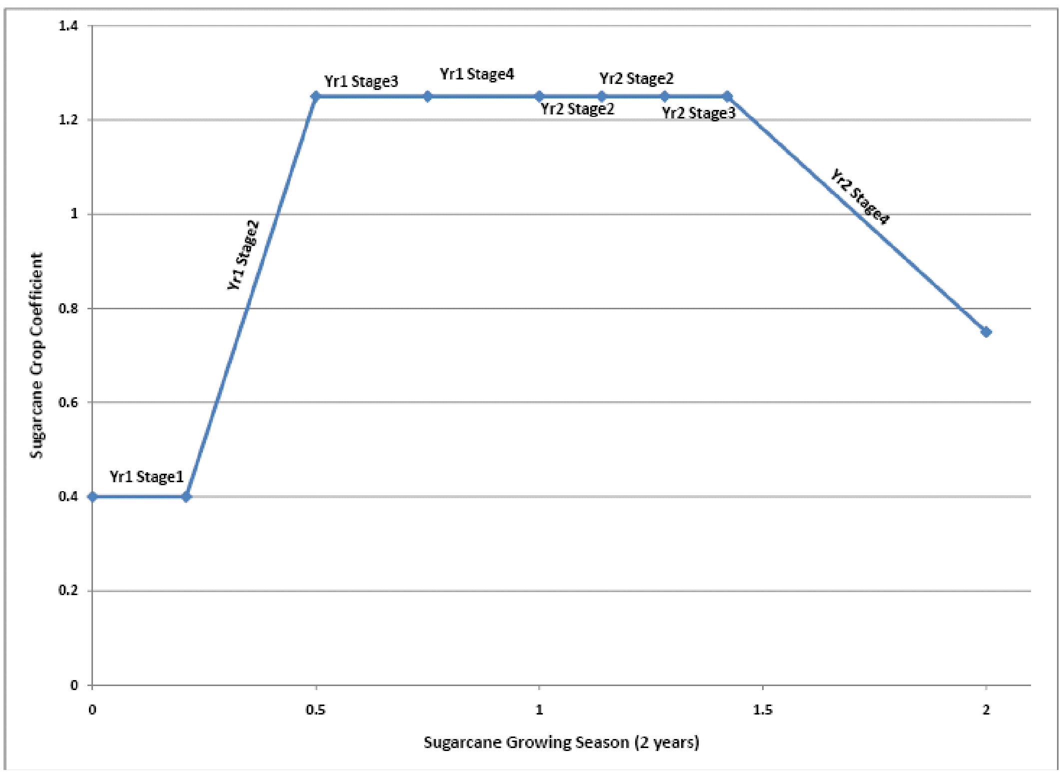

Figure 1. Changes in K_c values as a function of sugarcane's two-year crop cycle. As detailed in the preceding paragraphs, each year has four growth stages of different lengths and with different K_c values.

Calculating Optimal Irrigation Requirements

The model uses the following procedure to calculate optimal irrigation requirements:

1- Long term historical daily rainfall (P) and reference evapotranspiration (ET_o) values were obtained from historical weather data.

2- Daily surface water runoff (Q_{Runoff}) was calculated using the SCS curve number method with historical daily rainfall data.

3- Net rainfall (P_{net}) was calculated by subtracting surface water runoff from measured rainfall. P_{net} is the portion of rainfall that infiltrates the ground surface.

4- Crop evapotranspiration (ET_c) was calculated by multiplying crop coefficient (K_c) values, which change according to the growth stage, by ET_o.

5- Daily optimal irrigation requirements (IRR) were calculated using a water budget approach. Because HC&S claims to plant sugar year round, the model was run twelve times for each TMK to account for crops being planted in each month of the year (e.g., January, February, March, etc.). The IRR for each TMK (reflected in Tables 2 and 3) is an average of those figures to account for variations in IRR based on the month in which a crop was planted.

6- Statistical analysis was performed on the calculated historical IRR data set. Mean, median, maximum and minimum values, and several coefficients of variation of the IRR were calculated. These daily values were summed along the growing season of each crop to obtain weekly, monthly, seasonal or annual IRR values.

7- The calculated IRR data set was fitted to Type I Extreme Value Distribution for positive non-zero irrigation values using the least square curve fitting method to determine the IRR values having non-exceedance probabilities of 50%, 80%, 90% and 95%. This corresponds to an average climate year, 1 in 5 year, 1 in 10 year, and 1 in 20 year drought conditions, respectively.

Results of the Analysis

Optimal irrigation requirements were calculated for the three TMKs comprising HC&S's Waihee-Hopoi fields (Table 2) and the four TMKs comprising HC&S's Iao-Waikapu fields (Table 3). For each TMK, irrigation requirements were calculated for year 1 and year 2 of the sugarcane crop cycle using 54 years of rainfall data. The tables provide figures produced by this calculation.

For the Waihee-Hopoi fields, IRR ranged between 4,211 and 6,005 GAD, which represents the minimum and maximum over 54 years, respectively. HC&S's reported average use of 6,826 GAD is 62% and 14% higher than these minimum and maximum IRR values, respectively. The reported GAD of 6826 is 20% higher than the IRR value of 5,674 GAD that is based on an 80% probability of satisfying the crop's irrigation requirements. As previously explained, that figure is an industry standard used by government and the private sector to calculate crop water duties.

Table 2. Analysis of optimal irrigation requirements for the Waihee-Hopoi fields

TMK	Year	Acreage	MEAN	MED.	XMAX	XMIN	50%	80%	90%	95%
		Acres	GAD(Gallons Per Acre Per Day)							
238006003	1	1255	5162	5233	5989	4057	5213	5609	5786	5921
	2	1255	4955	5011	5780	3779	5006	5406	5586	5722
238005002	1	4409	5497	5550	6213	4484	5545	5893	6046	6160
	2	4409	5215	5266	5929	4151	5262	5610	5767	5883
238005003	1	425	5114	5170	5797	4138	5161	5494	5643	5755
	2	425	4854	4901	5563	3817	4901	5245	5400	5515
Weighted Average			**5269**	**5323**	**6005**	**4211**	**5317**	**5674**	**5834**	**5953**
Reported			**6,826**	**6,826**	**6,826**	**6,826**	**6,826**	**6826**	**6,826**	**6,826**
(Reported / Calculated)			**130%**	**128%**	**114%**	**162%**	**128%**	**120%**	**117%**	**115%**

For the Iao-Waikapu fields, the IRR ranged between 3,648 and 5,558 GAD, which represents the minimum and maximum over 54 years, respectively. HC&S's reported average use of 7,716 GAD is 112% and 39% higher than these minimum and maximum IRR values, respectively. The reported GAD of 7,716 is 50% higher than the IRR value of 5,150 GAD that is based on the industry standard of 80% probability of satisfying irrigation requirements. This 80% probability is used by Hawaii NRCS of the US Department of Agriculture in calculating crop water duties. It is also used by the agricultural irrigation industries in designing irrigation systems. An 80% probability means that there is a chance that in one of every five years the calculated IRR will be less than the optimal crop needs.

Table 3. Analysis of optimal irrigation requirements for the Iao-Waikapu fields

TMK	Year	Acreage	MEAN	MED.	XMAX	XMIN	50%	80%	90%	95%
		Acres	GAD (Gallons Per Acre Per Day)							
238005023	1	324	5,536	5,593	6,286	4,618	5,581	5,928	6,081	6,196
	2	324	5,191	5,239	5,932	4,268	5,236	5,575	5,728	5,843
236002003	1	621	4,908	4,953	5,748	3,854	4,953	5,352	5,530	5,667
	2	621	4,656	4,703	5,517	3,535	4,702	5,107	5,292	5,430
236002001	1	285	4,935	5,002	5,753	3,824	4,983	5,381	5,561	5,698
	2	285	4,722	4,771	5,574	3,511	4,772	5,184	5,370	5,510
236004003	1	657	4,364	4,405	5,255	3,346	4,404	4,811	4,995	5,136
	2	657	4,160	4,203	5,085	3,059	4,203	4,632	4,828	4,978
Weighted Average			**4,708**	**4,755**	**5,558**	**3,648**	**4,752**	**5,150**	**5,330**	**5,466**
Reported			**7,716**	**7,716**	**7,716**	**7,716**	**7,716**	**7,716**	**7,716**	**7,716**
(Reported / Calculated)			**164%**	**162%**	**139%**	**212%**	**162%**	**150%**	**145%**	**141%**

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