APPENDIX: Model Inputs

A Systems Approach for Investigating Water, Energy, and Food Scenarios in East-Central Maui

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November 2014

THE UNIVERSITY OF TEXAS AT AUSTIN

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1. Model Input Values

1.1 Model Inputs – Surface Water Module

1.1.1 Land Parcel Definitions and Input Parameters

Figure 1 shows the specification of land parcels (1–34) for the model focusing on Central Maui. The primary focus of the scenarios in this report is for land parcels 4–27.

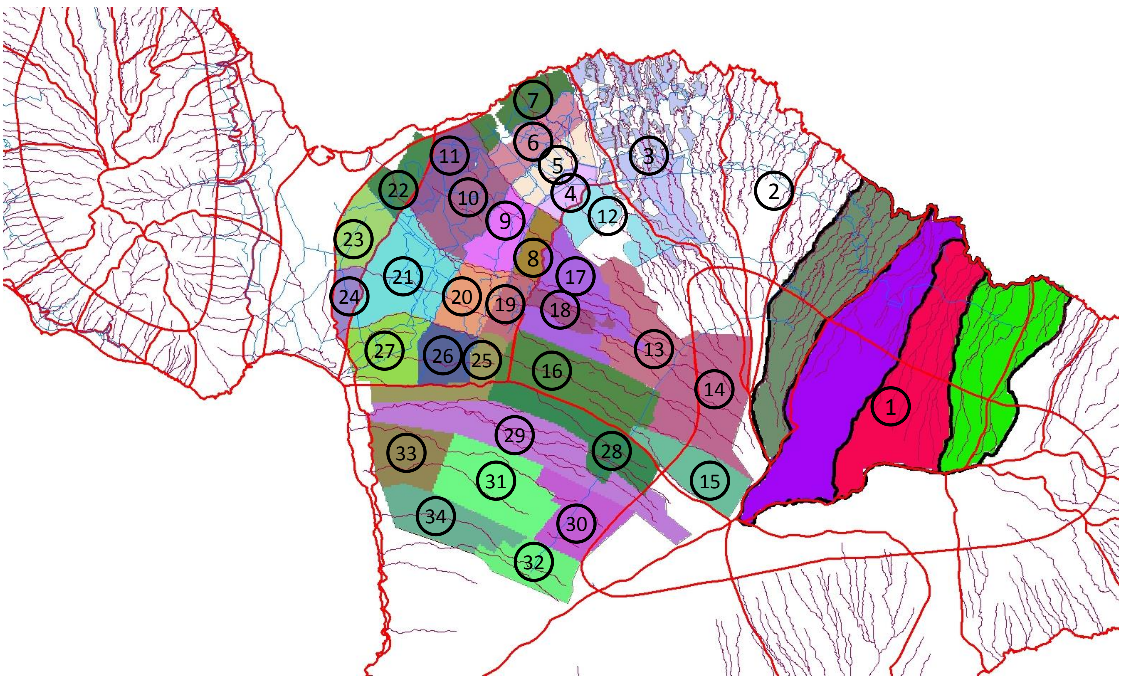

Figure 1. The land parcels designated for a the study of East-Central Maui.

1.1.1.1 Size of each land parcel

Table 1 lists the land area, in acres, of each land parcel modeled in the STELLA model.

Table 1. Land area of each land parcel.

	Parcel Area (acres)
Parcel 1	N/A
Parcel 2	N/A
Parcel 3	N/A
Parcel 4	1233
Parcel 5	2155
Parcel 6	2776
Parcel 7	2466
Parcel 8	1340
Parcel 9	2483
Parcel 10	3712
Parcel 11	2613
Parcel 12	2788
Parcel 13	4457
Parcel 14	7079
Parcel 15	3466
Parcel 16	5853
Parcel 17	5135
Parcel 18	1000*
Parcel 19	1519
Parcel 20	2545
Parcel 21	5845
Parcel 22	1941
Parcel 23	2459
Parcel 24	1227
Parcel 25	2758
Parcel 26	2245
Parcel 27	3523
Parcel 28	4478
Parcel 29	8025
Parcel 30	3702
Parcel 31	5838
Parcel 32	2789
Parcel 33	3320
Parcel 34	3842

* The area of Land Parcel 18 is 1,239 acres, but is modified in the STELLA model to 1,000 acres to use a "round number" for modeling diversified agricultural production on 1,000 acres.

1.1.1.2 Rainfall

Rainfall quantities for parcels 1-3 are not used for any calculations in the model, and thus are not listed. Monthly rainfall per parcel is estimated (i) summing raster approximations of rainfall within each land parcel and (ii) obtaining approximate values (e.g. near center of parcels) from the online interactive Rainfall Atlas map (http://rainfall.geography.hawaii.edu/).

Table 2. Average monthly rainfall per land parcel.

	Average Rainfall (inches/month)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Parcel 1	--	--	--	--	--	--	--	--	--	--	--	--
Parcel 2	--	--	--	--	--	--	--	--	--	--	--	--
Parcel 3	--	--	--	--	--	--	--	--	--	--	--	--
Parcel 4	5.40	4.28	5.19	4.56	1.87	0.98	1.76	1.63	0.92	1.97	4.33	5.52
Parcel 5	5.30	4.11	5.23	4.51	2.06	1.11	2.01	1.87	1.03	2.16	4.30	5.30
Parcel 6	4.84	3.54	4.61	3.81	1.82	1.04	1.92	1.77	0.97	2.12	3.90	4.68
Parcel 7	4.30	3.11	3.68	2.91	1.47	0.92	1.78	1.51	0.83	1.85	3.29	3.98
Parcel 8	5.85	4.32	5.28	3.76	2.33	1.15	1.44	1.42	1.21	1.88	4.43	6.01
Parcel 9	4.99	3.79	4.34	3.23	2.03	1.00	1.14	1.20	0.96	1.64	4.11	5.30
Parcel 10	3.99	2.89	2.72	1.89	1.18	0.60	0.59	0.70	0.51	1.01	2.91	3.85
Parcel 11	3.71	2.68	2.49	1.57	1.02	0.57	0.54	0.64	0.47	0.93	2.64	3.51
Parcel 12	6.39	5.66	6.65	5.97	2.40	1.30	2.29	2.22	1.27	2.49	5.60	7.18
Parcel 13	7.94	5.80	9.30	6.68	3.89	2.41	3.94	3.56	2.66	3.80	5.97	7.65
Parcel 14	7.59	5.77	6.94	5.23	3.07	2.23	3.03	2.82	2.71	3.10	5.58	7.02
Parcel 15	7.45	4.30	5.56	2.55	1.78	0.73	1.10	1.70	1.76	1.72	4.35	6.31
Parcel 16	4.45	3.34	4.00	2.96	1.98	1.33	1.52	1.43	1.25	1.76	3.25	4.09
Parcel 17	5.58	4.29	5.19	3.69	2.21	1.15	1.45	1.44	1.30	1.88	4.12	5.66
Parcel 18	4.81	3.57	4.16	2.83	1.80	0.91	1.13	1.18	1.07	1.53	3.33	4.62
Parcel 19	3.36	2.20	1.91	1.29	0.00	0.00	0.00	0.00	0.00	0.75	1.46	2.69
Parcel 20	3.02	2.01	1.65	1.02	0.00	0.00	0.00	0.00	0.00	0.12	1.20	2.51
Parcel 21	3.61	2.15	1.72	0.86	0.48	0.12	0.17	0.23	0.21	0.56	1.91	3.06
Parcel 22	3.40	2.38	2.13	1.16	0.71	0.35	0.35	0.42	0.29	0.82	2.34	3.22
Parcel 23	3.39	2.25	2.01	1.06	0.60	0.20	0.22	0.29	0.19	0.84	2.26	3.21
Parcel 24	3.00	1.92	1.05	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00
Parcel 25	2.77	1.63	1.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00
Parcel 26	3.00	1.87	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00
Parcel 27	2.81	1.35	1.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00
Parcel 28	3.93	2.88	2.67	1.76	1.48	0.94	0.87	0.95	1.17	1.30	2.80	3.66
Parcel 29	3.59	2.19	1.77	1.08	0.52	0.23	0.28	0.43	0.55	0.58	1.54	2.72
Parcel 30	4.93	2.91	2.72	2.57	1.72	0.95	0.98	1.12	1.83	1.73	2.05	3.54
Parcel 31	3.28	2.01	1.55	1.02	0.46	0.19	0.28	0.24	0.43	0.49	1.32	2.23
Parcel 32	5.01	2.85	2.79	2.57	1.64	0.90	1.00	1.04	1.73	1.76	1.96	3.53
Parcel 33	2.89	1.01	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00
Parcel 34	3.10	1.53	1.41	0.62	0.31	0.03	0.13	0.11	0.25	0.36	1.07	2.05

1.1.1.3 Reference evapotranspiration (ET_o)

For land parcels 4-11, 19-24, and 27 that approximately represent lands owned by Hawaiian Commercial and Sugar (HC&S), ET_o is assumed the same on all parcels and equal to values from Exhibit G-1 of (CWRM, 2010). For all other land parcels, ETo is approximated from data in (Engott and Vana, 2007): Figure 8 (pan evaporation), Table 8 (pan coefficient = 0.85 for all non-sugar cane, = 0.8 for sugar cane), and distributed monthly using Table 7 (ratio of monthly-to-annual pan evaporation).

Table 3. Reference evapotranspiration per month per land parcel (Parcels 1-3 not modeled).

	Reference Evapotranspiration (inches/month)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Parcel 4	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 5	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 6	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 7	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 8	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 9	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 10	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 11	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 12	2.76	3.32	3.87	4.42	4.97	6.08	6.63	6.08	5.53	4.42	3.87	3.32
Parcel 13	2.98	3.83	3.40	3.83	4.25	4.25	3.83	3.83	3.83	2.98	2.55	2.55
Parcel 14	3.57	4.59	4.08	4.59	5.10	5.10	4.59	4.59	4.59	3.57	3.06	3.06
Parcel 15	3.57	4.59	4.08	4.59	5.10	5.10	4.59	4.59	4.59	3.57	3.06	3.06
Parcel 16	2.64	3.16	3.69	4.22	4.74	5.80	6.32	5.80	5.27	4.22	3.69	3.16
Parcel 17	2.98	3.57	4.17	4.76	5.36	6.55	7.14	6.55	5.95	4.76	4.17	3.57
Parcel 18	2.98	3.57	4.17	4.76	5.36	6.55	7.14	6.55	5.95	4.76	4.17	3.57
Parcel 19	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 20	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 21	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 22	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 23	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 24	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 25	4.29	4.24	5.50	6.39	7.76	8.29	8.60	8.55	6.89	5.94	4.53	4.05
Parcel 26	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 27	5.15	4.90	6.24	7.04	8.56	9.56	10.09	9.88	8.99	7.67	6.59	5.34
Parcel 28	2.98	3.57	4.17	4.76	5.36	6.55	7.14	6.55	5.95	4.76	4.17	3.57
Parcel 29	3.40	4.08	4.76	5.44	6.12	7.48	8.16	7.48	6.80	5.44	4.76	4.08
Parcel 30	3.27	4.21	3.74	4.21	4.68	4.68	4.21	4.21	4.21	3.27	2.81	2.81
Parcel 31	2.76	3.32	3.87	4.42	4.97	6.08	6.63	6.08	5.53	4.42	3.87	3.32
Parcel 32	3.27	4.21	3.74	4.21	4.68	4.68	4.21	4.21	4.21	3.27	2.81	2.81
Parcel 33	3.61	4.34	5.06	5.78	6.50	7.95	8.67	7.95	7.23	5.78	5.06	4.34
Parcel 34	4.46	5.74	5.10	5.74	6.38	6.38	5.74	5.74	5.74	4.46	3.83	3.83

1.1.2 Irrigation Ditch Inflows

Irrigation ditch inflow is assumed to come from five irrigation ditches: Hamakua, Wailoa (Kauhikoa), Lowrie, Haiku, and Upcountry (Kula). There are three sets of irrigation ditch inflows relating to different simulation scenarios: Calibration, Average, and Drought.

1.1.2.1 Calibration Scenario

The calibration scenario is used to compare model results to information provided by Hawaiian Commercial and Sugar (HC&S) to the Hawaii Commission on Water Resources Management regarding operation of 30,000 acres of sugar cane cropland in Central Maui that are served by the East Maui Irrigation system (CWRM, 2010). The flows listed in Table 4 from Exhibit G-1 are stated as the average surface water deliveries to HC&S from 1986-2009.

Table 4. "Calibration" flows assumed for irrigation ditches in East Maui Irrigation system (units: million gallons per day). Source: Exhibit G-1 of (CWRM, 2010).

	Wailoa (assume turns into Kauhikoa)	Hamakua	Lowrie	Haiku
January	0	145.4	0	0
February	0	128.6	0	0
March	0	153.6	0	0
April	0	188.3	0	0
May	0	167.8	0	0
June	0	148.4	0	0
July	0	183.8	0	0
August	0	173.2	0	0
September	0	137.1	0	0
October	0	145.3	0	0
November	0	168.4	0	0
December	0	160.3	0	0

1.1.2.2 Average Irrigation Ditch Scenarios

For running simulations for scenarios with average irrigation ditch flows, the flows in Table 5 are aggregated into the single ditch New Hamakua (because it resides at the highest elevation and enters at Land Parcel 4 making it able to access all higher-numbered land parcels per the convention and definitions of the STELLA model mathematics: see full model documentation and Section 1.1.3 on Ditch Connectivity).

The mean monthly ditch flows for the Wailoa ditch flow come from the USGS stream gauge database for gauge number 16588000 at Honopou stream near Huelo, Maui. Annual mean flow data were also obtained for New Hamakua ditch (USGS gauge: 16589000), Lowrie ditch (USGS gauge: 16592000), and Haiku ditch (USGS gauge: 16594000). As there are more extensive monthly data available for the Wailoa mean flows (from 1922 to 1987) than for the other three ditches, each of the monthly average flows for New Hamakua is taken as a constant fraction of the mean Wailoa flow rate. The constant fractions for New Hamakua, Lowrie, and Haiku ditches are calculated as the average of the annual mean flow ratios in the ditch relative to the annual mean flow in the Wailoa ditch. For example, accounting for all years for which there are irrigation ditch flow data for both the Wailoa and Lowrie ditches, the mean annual flow in the Lowrie ditch is *on average* 15.9% of the mean annual flow rate in the Wailoa ditch.

Table 5. Average flows assumed for irrigation ditches in East Maui Irrigation system (units: million gallons per day). The flows in the New Hamakua, Lowrie, and Haiku ditches are assumed to be a constant fraction of the flow in the Wailoa ditch. ***For running the STELLA model, all four flows are aggregated into a single ditch flow.***

	Wailoa (assume turns into Kauhikoa) (USGS gauge: 16588000)	New Hamakua (19.1% of Wailoa)	Lowrie (15.9% of Wailoa)	Haiku (8.4% of Wailoa)
January	87.1	16.6	13.8	7.3
February	84.2	16.1	13.4	7.1
March	121.3	23.1	19.3	10.2
April	135.3	25.8	21.5	11.4
May	128.5	24.5	20.4	10.8
June	96.3	18.4	15.3	8.1
July	122.1	23.3	19.4	10.3
August	120.7	23.0	19.2	10.2
September	85.7	16.4	13.6	7.2
October	93.6	17.9	14.9	7.9
November	115.0	22.0	18.3	9.7
December	104.3	19.9	16.6	8.8

1.1.2.3 Drought (low) Flow Irrigation Ditch Scenarios

During discussions with stakeholders and subject matter experts while performing the studies in this report, many of the stakeholders expressed a desire to have a future climate and/or drought scenario. Here a drought scenario is defined by assuming EMI ditch flows of 1962 (based upon the average monthly flows in the Wailoa ditch). Lower EMI ditch flows translate to lower surface water availability for crops in Central Maui.

Lower surface water diversion into the EMI system translates to increased groundwater pumping to irrigate crops *if* crops are to be provided all water for total evapotranspiration needs. **Error! Reference source not found.** shows the monthly water balance for the four 'system' Energy & Food scenarios when assuming an estimate of the lower EMI ditch flows of 1962. Compared to the results for average ditch inflows in **Error! Reference source not found.**, these low flow scenarios require larger quantities of groundwater extraction, particularly in the summer months. The 1962 Wailoa ditch flow is lower than the average Wailoa ditch flow for all months except March. The estimated annual surface water delivery from the EMI system in the average year is 58 Bgal/yr versus 42 Bgal/yr (28% less than average) for estimated 1962 deliveries. The energy and food production is assumed the same as in the scenarios with average EMI ditch flows.

Table 6. Assumed flows for a ***low flow*** scenario for irrigation ditches in East Maui Irrigation system (units: million gallons per day). Wailoa ditch flow data are for the year 1962. ***For running the STELLA model, all four flows are aggregated into a single ditch flow.***

	Wailoa (assume turns into Kauhikoa) (USGS gauge: 16588000)	New Hamakua (19.1% of Wailoa)	Lowrie (15.9% of Wailoa)	Haiku (8.4% of Wailoa)
January	51.3	9.8	8.2	4.3
February	48.2	9.2	7.6	4.1
March	162.5	31.0	25.8	13.7
April	95.5	18.2	15.2	8.1
May	98.1	18.7	15.6	8.3
June	34.4	6.6	5.5	2.9
July	87.8	16.8	13.9	7.4
August	94.7	18.1	15.0	8.0
September	73.9	14.1	11.7	6.2
October	51.1	9.7	8.1	4.3
November	49.7	9.5	7.9	4.2
December	79.2	15.1	12.6	6.7

1.1.3 Ditch Connectivity

For simplicity, each simulation result discussed in this report assumes that the flows in all four ditches serving HC&S lands are summed into one ditch (Hamakua in the model) that can serve most land parcels below the Upcountry. The Hamakua ditch enters at land parcel 4, and the assumed 'master'

Hamakua ditch can serve land parcels 4-12, 19-24, 26, and 27 as represented by the "HamakuaDitchConnectivityMatrix". The Kauhikoa, Lowrie, and Haiku connectivity matrices have all zero elements. The Upcountry ditch represents the Kula ditch and assumes that it can enters at land parcel 16 and can reach land parcels 16-18, 28-31, and 32.

Hamakua Ditch Connectivity Matrix: Recall from model documentation that a value in row *i* and column *j* means that irrigation flows into land parcel *j* flow immediately or eventually into land parcel *i*. Each row and column represents a land parcel (the matrix is 34 x 34). All values in the blacked-out cells are zero (by definition).

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Upcountry Ditch Connectivity Matrix. Recall from model documentation that a value in row *i* and column *j* means that irrigation flows into land parcel *j* flow immediately or eventually into land parcel *i*. Each row and column represents a land parcel (the matrix is 34 x 34). All values in the blacked-out cells are zero (by definition).

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0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1																	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0													
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0												
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0							
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1						
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0			
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

1.1.4 Surface Water Runoff

Surface water runoff is that water from rainfall that does not go to aquifer recharge or evapotranspiration from vegetation or cropland. Surface water runoff for all parcels and all months is assumed zero given that the runoff for Region 4 (representing Central Maui) of Table 6 and Figure 7 in (Engott and Vana, 2007) is 0%–2% of rainfall for all months except March when it is 5%. The runoff information from (Engott and Vana, 2007) for Region 4 (see Figure 7 of that document) does not cover most of the land of interest for this model. However, the inherent assumption for the modeled scenarios of this report is that runoff in the leeward side of Haleakala Mountain is insignificant within the accuracy of other parameters used in the model.

Runoff is assumed zero for all parcels modeled with crops. Runoff is very significant in Land Parcels 1-3 that are the source of irrigation ditch flows, but no crops are modeled in those parcels.

1.2 Model Inputs – Groundwater Module

1.2.1 Groundwater Pumping

Forty groundwater pumps are (potentially) separately modeled in the STELLA Central Maui model. Groundwater pumps 1-39 (see Table 7) represent those reported by HC&S to the CWRM as serving their approximate 30,000 acres on the eastern (Haleakala) side of the Central Maui valley (CWRM, 2010).

Groundwater pump 40 is an added *hypothetical groundwater pump* that serves Upcountry irrigation needs. In other words, all groundwater pumping needs for the Upcountry are assumed served by groundwater pump 40 that represents the general characteristics of an Upcountry groundwater well. Pump 40 is modeled at Land Parcel 13 because that is the assumed beginning of the Upcountry Ditch (see Upcountry Ditch Connectivity Matrix in Section 1.1.3). In this way, groundwater pump 40 can provide water to all land parcels that can receive water as modeled for the Upcountry irrigation ditch.

Table 7. Land parcels that are served by each groundwater pump (specified by pump number).

Land Parcel	Groundwater pumps serving parcel	"Owner" of groundwater well
5	32, 33	HC&S
6	29	HC&S
7	22-28, 30-31	HC&S
11	2-4, 8, 20-21	HC&S
22	10-12	HC&S
23	13-19, 34-39	HC&S
26	5-7	HC&S
27	1	HC&S
13	*40*	*None (hypothetical well)*

In the STELLA model, the element "GroundwaterWellMatrix" specifies the information summarized in Table 7. The "GroundwaterWellMatrix" is a matrix of dimensions (Land Parcel × Groundwater pump, here 34 x 40). In the "GroundwaterWellMatrix", a value of 1 should be input indicating to which land parcel each groundwater well pumps water. For example, if groundwater well number 32 pumps water to land parcel 5, cell (5, 32) of "GroundwaterWellMatrix" should have a value of 1 and all other cells in column 1 should be zero.

Table 8. The "GroundwaterWellMatrix" used in the simulated scenarios. There are 34 rows representing each land parcel and 40 columns representing each groundwater well.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.2.1.1 Specifying Groundwater Well to Aquifer Connectivity

In the STELLA model, the element "AquiferWellMatrix" specifies the aquifer from which each groundwater pump extracts water. The "AquiferWellMatrix" is a matrix of dimensions (Aquifer × Groundwater pump, here 5 x 40). In the "AquiferWellMatrix", a value of 1 should be input indicating from which aquifer each groundwater well pumps water.

Table 9. The "AquiferWellMatrix" used in the simulated scenarios. There are 5 rows representing each aquifer and 40 columns representing each groundwater well.

GW Well →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1: Paia	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
2: Kamaole	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3: Kahului	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0
4: Makawao	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5: Koolau	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.2.1.2 Electricity and capacity for groundwater pumping

Table 10 lists the quantity of electricity required to pump water (kWh/million gallons) and pumping capacity (millions of gallons per day) used for each groundwater pump. Data for pumps 1-39 are from (CWRM, 2010). The electricity need of 7,000 kWh/MG for hypothetical pump 40 is estimated from The University of Texas at Austin Master's Thesis of Emily Grubert stating 5,000 to 10,000 kWh/MG needed for Upcountry groundwater supply. This wide range was estimated from (CWRM, 2010, Grubert, 2011) discussion of the Pookela Well with 7 MGD in capacity and reported costs of $1.75/1000 gallon in electricity costs. If the rate of electricity is assumed at $0.25/kWh to $0.34/kWh, this range translates to approximately 5,000 to 7,000 kWh/MG of water pumped from the Makawao aquifer. The value of 7,000 kWh/MG was chosen to estimate the electricity need near the middle to upper range of the likely range. The groundwater pump 40 capacity of 100 MGD is arbitrarily chosen to be large enough to serve the needs of the scenarios. New pumps might have to be installed to meet the modeled Upcountry groundwater pumping demands.

Table 10. The electricity (kWh/MG) needs and capacity (MGD) *of groundwater extraction* for each groundwater pump used to model the scenarios of this report.

GW Well →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Electricity	1111	740	830	360	1800	1820	300	1490	1200	910	720	670	570	560	260	780	790	820	1140	1170
Capacity	4.32	0	1.62	16.8	9.34	1.23	8	8.88	9	9.2	6.07	8.93	1.61	17.24	13.88	4.61	4.57	4.39	0.33	12.33

Table 10 (continued).

GW Well →	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Electricity	830	1060	1060	1530	1080	1080	1090	1260	1070	1570	1360	1840	2310	660	670	600	600	960	980	7000
Capacity	7.26	3.39	3.39	7.08	5	5	1.95	8.57	10.12	6.18	3	13.01	13.48	1.47	1.38	4	4	5	5	100

As discussed in the main body of the report describing the calibration scenarios, the modeling in this report calculates a *lower* quantity of groundwater pumping that reported by HC&S in Exhibit E-2: HC&S Brackish Groundwater Well Information in (CWRM, 2010) (see Table 11). Some of the pumps described in Exhibit E-2 are listed as "booster pumps". The author interprets these booster pumps to be those that move water *already at the surface* from one area to another. This interpretation leads the author to reduce the stated pumping capacity of pumps that are connected to booster pumps in order not to overestimate the quantity of groundwater that is actually extracted, as groundwater extraction is the primary quantity of interest. Thus, the groundwater pump capacity (assumed in the STELLA model as "groundwater extraction capacity") of booster pumps is subtracted from the capacity of non-booster pumps that feed into the booster pumps.

Table 11. The electricity needs (kWh/MG) and capacity (MGD) for each groundwater pump as reported in (CWRM, 2010).

GW Well →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Electricity	1111	740	830	360	1800	1820	300	1490	1200	910	720	670	570	560	260	780	790	820	1140	1170
Capacity	4.32	9.77	8.65	16.8	9.34	9.23	8	8.88	9	9.2	15	8.93	18.9	17.24	13.88	4.61	4.57	4.39	12.7	12.33

Table 11 (continued).

GW Well →	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Electricity	830	1060	1060	1530	1080	1080	1090	1260	1070	1570	1360	1840	2310	660	670	600	600	960	980
Capacity	7.26	3.39	3.39	7.08	5	5	12.1	8.57	10.12	9.18	3	13.01	13.48	5.47	5.38	4	4	5	5

The booster pumps reported in Exhibit E-2 refer to the following pump numbers per Table 10 and Table 11:

- Booster pump 4 is served by groundwater extraction pumps 2 and 3.
- Booster pump 7 is served by groundwater extraction pumps 5 and 6.
- Booster pump 12 is served by groundwater extraction pumps 9, 10, and 11.
- Booster pump 15 is served by groundwater extraction pumps 13 and 14.
- Booster pumps 20 and 21 are served by groundwater extraction pump 19.
- Booster pump 29 is served by groundwater extraction pumps 27 and 28.
- Booster pump 31 is served by groundwater extraction pump 30.
- Booster pumps 36-39 are served by groundwater extraction pumps 34 and 35.

1.2.1.3 Groundwater well pump capacity factor

As described in the main body of this paper, the capacity factor for each groundwater pump varies as required to meet the water demands of each scenario. For simplicity, and based upon the land parcels location of each pump, the groundwater pumps were grouped into nine subsets that are assumed to have the same capacity factor for any given scenario:

- 1
- 2-4, 8, 20-28, 30, 31
- 5-7
- 9 (a pump listed in (CWRM, 2010) as no longer in use)
- 10-12
- 13-19, 34-39
- 29
- 32-33
- 40

1.3 Model Inputs – Agriculture Module

1.3.1 Crop coefficient (Kc)

The crop coefficient Kc, most simply expressed as a single value based on the stage of growth of the crop, expresses the difference in evapotranspiration between the crop and reference grass surface that is assumed in calculating ET_o. For reference see Chapter 6 of (FAO, 2004). If there is no crop planted for a given month for a given parcel, then the default crop coefficient is Kc = 1 but that land is assumed to need no irrigation. Table 12 lists Kc for each crop in the model.

Table 12. Monthly crop evapotranspiration coefficients used to determine water demand for crops. These crop coefficients include assumptions for planting and harvesting cycles.

	Sugar Cane	Sweet Sorghum	Diversified Ag	Kikuyu Grass (pasture grass)	Native	Cassava	Banagrass
January	1.00	0.00	0.864	1	1	0.66	1.00
February	1.00	0.08	0.406	1	1	0.66	1.00
March	1.00	0.21	0.300	1	1	0.66	1.00
April	1.00	0.34	0.389	1	1	0.66	1.00
May	1.00	0.68	0.805	1	1	0.66	1.00
June	1.00	0.68	1.017	1	1	0.66	1.00
July	1.00	0.68	0.889	1	1	0.66	1.00
August	1.00	0.68	0.406	1	1	0.66	1.00
September	1.00	0.68	0.300	1	1	0.66	1.00
October	1.00	0.34	0.339	1	1	0.66	1.00
November	1.00	0.25	0.755	1	1	0.66	1.00
December	1.00	0.13	0.967	1	1	0.66	1.00

1.3.1.1 Sugar Cane

Sugar cane Kc is modeled on a 24-month crop cycle to approximate the current practice of sugar cane harvesting on Maui (see Table 13). The values in Table 13 indicate the crop water need as it matures through its stages of development from planting to harvest (in month 22). A fallow period of 2 months is assumed at the end of the crop cycle (months 23 and 24).

The monthly Kc for sugar cane as represented in Table 12 is calculated from the monthly single crop cycle in Table 13 by repeating the information in Table 13 for 24 months with the pattern offset 1 month for each of the 24 months. For example, if sugar cane crop 1 was planted in month 1 with Kc=0.4, it would have Kc=0.66 in month 2. A second sugar cane crop would then be planted in month 2 with

Kc=0.4 in month 2 and Kc-0.66 in month 3. And so on. The total sugar cane crop Kc for a given month is taken as the average of the 24 individual Kc values for the crop in that month.

Table 13. The monthly crop coefficient for each modeled crop is an average of multiple successions of the "single land crop cycle" shown in this table. Data are from the United Nations Food and Agriculture Organization (FAO, 2004).

	Sugar Cane	Sweet Sorghum, 1 planting (full growth)	Sweet Sorghum, 3 plantings (at full growth)	Multiplying factor to approximate low Sorghum yields in HI trials	Total Kc for sweet sorghum crop
month 1	0.40	0.75	0.000	0.33	0.00
month 2	0.66	1.15	0.250	0.33	0.08
month 3	1.14	1.16	0.633	0.33	0.21
month 4	1.25	--	1.021	0.33	0.34
month 5	1.25	--	1.021	0.67	0.68
month 6	1.25	--	1.021	0.67	0.68
month 7	1.25	--	1.021	0.67	0.68
month 8	1.25	--	1.021	0.67	0.68
month 9	1.25	--	1.021	0.67	0.68
month 10	1.25	--	1.021	0.33	0.34
month 11	1.25	--	0.771	0.33	0.25
month 12	1.25	--	0.388	0.33	0.13
month 13	1.25	--	--	--	
month 14	1.25	--	--	--	
month 15	1.25	--	--	--	
month 16	1.25	--	--	--	
month 17	1.25	--	--	--	
month 18	1.25	--	--	--	
month 19	1.25	--	--	--	
month 20	1.04	--	--	--	
month 21	0.83	--	--	--	
month 22	0.00	--	--	--	
month 23	0.00	--	--	--	
month 24	0.00	--	--	--	

1.3.1.2 Sweet Sorghum

Sweet sorghum Kc is modeled on a 3-month crop cycle to approximate one future option for sweet sorghum harvesting on Maui, and Hawai'i more generally (see Table 13). The values in Table 13 indicate the crop water need as it matures through its stages of development from planting (month 1) to harvest (in month 3).

The monthly Kc for sweet sorghum as represented in Table 12 is calculated from the monthly single crop cycle in Table 13 by repeating the information in Table 13 three times at 3 month intervals. Thus, each sweet sorghum harvest is assumed 3 months after the previous harvest. For any given land parcel, the model assumes sweet sorghum is planted in 3 monthly intervals such that the 1/3 of the total planted sorghum is harvested each month. Thus, the model assumes for any given land parcel that sweet sorghum is planted in February, March, and April to be harvested in April, May, June. The second harvest occurs in July, August, and September, and the third harvest occurs in October, November, and December. This is represented by the Kc in Table 13 in the third column of data ("Sweet Sorghum, 3 plantings").

From communications with University of Hawaii researchers and crop trials, it has been determined that sweet sorghum does not grow (to any significant degree) during the winter months due to shorter days (personal communication with Andrew Hashimoto, (Hashimoto, 2012, Hashimoto et al., 2012)). Because recent crop trials in Hawai'i indicate substantially lower yields than occur for summer crops in more northern latitudes (e.g. Central Plains and Midwest United States), I adjust the Kc values downward to account for the lack of growth, and thus lack of evapotranspiration that would occur with less growth. The sorghum Kc "multiplying factors" in Table 13 are used to scale down the Kc for sweet sorghum (rightmost column of Table 13 and also in Table 12). This ***downscaling of Kc is highly approximate and uncertain*** as the author knows of no measurement data from real crop trials that can estimate the actual ET from sweet sorghum grown in Hawai'i. The total crop Kc for sweet sorghum is the average of the three individual crop cycle plantings for any given month.

1.3.1.3 Diversified Agriculture

The calculation of crop coefficients for diversified agriculture is a multi-step process, similar to that for other crops modeled in this report. There is an additional step of estimating Kc for each of the four types of crops modeled dry onions, bananas, cabbage, and lettuce. The model of diversified agriculture production assumes that 25% of the land is used for each of the four diversified agriculture crops. This 25% is the STELLA input value for the factor <u>DivAgPct</u>.

Table 14 shows the assumed planting and harvest schedule as taken from the Hawaii Agriculture Water Use and Development Plan (CTAHR, 2008). Dry onions are assumed planted in October and April and harvested in February and August, respectively. Bananas are modeled as a ratoon crop started in October. Cabbage is planted in November and

Table 14. The assumed planting and harvest time for each of the diversified agriculture crops.

	Dry Onions	Bananas (ratoon)	Cabbage	Lettuce
% of land for crop (DivAgPct)	25%	25%	25%	25%
Crop 1 plant	Oct. 15	Oct. 1	Nov. 1	Nov. 15
Crop 1 harvest	Feb. 15	Sept. 30	Feb. 1	Jan. 15
Crop 2 plant	Apr. 15	--	May 1	May 15
Crop 2 harvest	Aug. 15	--	Aug. 1	July 15
Hawaii crop length (approximate number of days)	122	365	92	60

Table 15 shows the crop stage lengths and crop coefficients for each crop stage from the FAO guidelines (FAO, 2004). The initial stage has the value of Kc_init. The development stage is the time period when the Kc linearly changes from Kc_init to Kc_mid. The middle stage remains at Kc_mid. The late stage Kc linearly changes from Kc_mid to Kc_end.

Table 15. The length of crop stage and crop coefficient for each crop growth stage (init = initial crop growth, mid = middle growth stage, end = end of crop growth) used for modeling diversified agriculture (FAO, 2004).

	Dry Onions	Bananas (2nd yr, Mediterranean, Feb plant)	Cabbage (Calif. Desert, Sept plant)	Lettuce (Mediterranean, Nov. plant)
Initial stage (L_init), Days	12	120	22	17
Development stage (L_dev), days	20	60	33	23
Middle stage (L_mid), days	57	180	28	14
Late stage (L_late), days	33	5	8	6
Total days	150	365	165	105
Initial stage (Kc_ini)	0.7	1	0.7	0.7
Development stage (Kc_mid)	1.05	1.2	1.05	1
Middle stage (Kc_end)	0.75	1.1	0.95	0.95

The monthly-weighted Kc values for each crop planting and harvest of diversified agriculture crops are shown in Table 16. Table 17 indicates the Kc per crop weighted by the percentage of land (25%) for each crop as well as the total Kc used, per month, for the modeled category of 'diversified agriculture'.

Table 16. Monthly Kc values for each diversified agriculture crop for both crop planting and harvest cycles for onions, cabbage, and lettuce. There is only one harvest assumed for bananas.

Monthly Kc (Crop 1)	Dry Onions	Bananas	Cabbage	Lettuce
January	0.97	1.10	0.95	0.44
February	0.43	1.20	0	0
March	0	1.20	0	0
April	0	1.20	0	0
May	0	1.20	0	0
June	0	1.20	0	0
July	0	1.20	0	0
August	0	1.20	0	0
September	0	1.20	0	0
October	0.35	1.00	0	0
November	0.96	1.00	0.72	0.34
December	1.05	1.00	0.95	0.87
Monthly Kc (Crop 2, if applicable)	Dry Onions	Bananas	Cabbage	Lettuce
January	0	--	0	0
February	0	--	0	0
March	0	--	0	0
April	0.35	--	0	0
May	0.96	--	0.72	0.34
June	1.05	--	0.95	0.87
July	0.97	--	0.95	0.44
August	0.43	--	0	0
September	0	--	0	0
October	0	--	0	0
November	0	--	0	0
December	0	--	0	0

Table 17. Monthly Kc values (weighted by the % of diversified agriculture land used for each crop) for each diversified agriculture crop as well as the total Kc per month assumed for the modeled category of "Diversified Agriculture" (far right column) that is the sum of the other four columns.

Weighted Kc per month per crop	Dry Onions	Bananas	Cabbage	Lettuce	Total Diversified Agriculture
January	0.24	0.28	0.24	0.11	0.86
February	0.11	0.30	0.00	0.00	0.41
March	0.00	0.30	0.00	0.00	0.30
April	0.09	0.30	0.00	0.00	0.39
May	0.24	0.30	0.18	0.08	0.81
June	0.26	0.30	0.24	0.22	1.02
July	0.24	0.30	0.24	0.11	0.89
August	0.11	0.30	0.00	0.00	0.41
September	0.00	0.30	0.00	0.00	0.30
October	0.09	0.25	0.00	0.00	0.34
November	0.24	0.25	0.18	0.08	0.76
December	0.26	0.25	0.24	0.22	0.97

1.3.1.4 Kikuyu grass (grass for pasture)

Kikuyu grass modeled as an example forage grass for cattle. The crop coefficient for kikuyu is assumed as Kc=1 for all months, the same as vegetation for reference evapotranspiration (ETo).

1.3.1.5 Cassava

The crop coefficients and growth cycle parameters for cassava are taken from the FAO guidelines (see Table 18) (FAO, 2004). Since each cassava crop is assumed to take 210 days, a second crop is assumed planted immediately after harvest to approximate a continuous 12-month rotation of cassava. Inherently, each land parcel growing cassava is assumed to plant and harvest 1/12 of the land during each month for continuous operation. . Thus, the Kc profile in the right-most column of Table 19 is offset by 1 month for each month, and the overall cassava crop Kc per month is taken as the average of the twelve monthly Kc profiles (each offset by 1 month) such that each month ends up with the same average Kc = 0.66 for each month.

Table 18. Cassava Kc values by stage and length of each crop growth stage (FAO, 2004).

	Kc			Length (days) of crop stage				
	Init	Mid	End	Init	Devel.	Mid	Late	TOTAL
Cassava	0.3	0.8	0.3	20	40	90	60	210

Table 19. Cassava Kc values for single crop cycles and total cassava crop as modeled in this study.

Cassava Crop (single crop plant-to-harvest profile)	Cassava Crop 1 (on single land piece)	Cassava Crop 2 (on single land piece)	Total Cassava Crop for a particular piece of land
0.36	0.36	0	0.36
0.49	0.49	0	0.49
0.84	0.84	0	0.84
0.84	0.84	0	0.84
0.84	0.84	0	0.84
0.71	0.71	0	0.71
0.45	0.45	0	0.45
0	0	0.36	0.36
0	0	0.49	0.49
0	0	0.84	0.84
0	0	0.84	0.84
0	0	0.84	0.84

1.3.1.6 Banagrass

Banagrass is assumed to have the same Kc as sugar cane.

1.3.2 Acres irrigated (IrrAcres, %)

For a given assumed crop planting, harvesting, and irrigation schedule, the user might choose to specify what percentage of the total acreage of a land parcel, specified to grow a certain crop, is actually under irrigation for any given month. For example, if you wish to model a given crop such that half of a land parcel is planted in January, and the other half is planted in February, then you could put a value of 0.5 for January for the land parcel being planted with that crop, and a value of 1 for February for the land parcel being planted with that crop. Correspondingly, if the "first" half of the crop is harvested in May and the "second" half is harvested in June, then IrrAcres = 0.5 for May and IrrAcres = 0.5 for June. If there is no crop planted for a given month for a given parcel, then the default IrrAcres = 0 for each month for that parcel.

For all of the crops modeled in this report, it is assumed that all land with a crop planted will be irrigated if rainfall is not sufficient to meet crop evapotranspiration (ETc).

Table 20. The percentage of land with a given crop that is assumed to be irrigated each month. By definition, "native" is not a modeled crop and assumed to be natural (or existing) vegetation that is not irrigated or cultivated.

	Sugar Cane	Sweet Sorghum	Diversified Ag	Kikuyu Grass	Native	Cassava	Banagrass
January	1	1	1	1	0	1	1
February	1	1	1	1	0	1	1
March	1	1	1	1	0	1	1
April	1	1	1	1	0	1	1
May	1	1	1	1	0	1	1
June	1	1	1	1	0	1	1
July	1	1	1	1	0	1	1
August	1	1	1	1	0	1	1
September	1	1	1	1	0	1	1
October	1	1	1	1	0	1	1
November	1	1	1	1	0	1	1
December	1	1	1	1	0	1	1

1.3.3 Irrigation efficiency (IrrEfficiency, %)

Not all of the water delivered via irrigation is transpired by the crop. This element captures that aspect of of irrigation systems and the specification of this value is informed by experience in practice (e.g. using drip irrigation systems) or other modeling efforts. Due to the model assumptions (mathematics), this irrigation efficiency factor is the *only* mechanism by which irrigation water can be modeled to infiltrate the soil into aquifers (either when applied as irrigation or delivered in and stored in irrigation ditches and reservoirs). Drip irrigation is assumed at 80% efficient for all crops besides kikuyu grass (
Table 21) (Engott and Vana, 2007). For kikuyu grass, or grass for pasture, the efficiency is assumed slightly less due the assumed use of some use of sprinkler irrigation.

Table 21. Irrigation efficiency for each modeled crop. The value of 0.8 (80%) represents an assumption of drip irrigation for each crop besides kikuyu grass. Kikuyu grass is assumed to have some sprinkler irrigation that lowers efficiency.

	Sugar Cane	Sweet Sorghum	Diversified Ag	Kikuyu Grass	Native	Cassava	Banagrass
January	0.80	0.80	0.8	0.75	1	0.8	0.8
February	0.80	0.80	0.8	0.75	1	0.8	0.8
March	0.80	0.80	0.8	0.75	1	0.8	0.8
April	0.80	0.80	0.8	0.75	1	0.8	0.8
May	0.80	0.80	0.8	0.75	1	0.8	0.8
June	0.80	0.80	0.8	0.75	1	0.8	0.8
July	0.80	0.80	0.8	0.75	1	0.8	0.8
August	0.80	0.80	0.8	0.75	1	0.8	0.8
September	0.80	0.80	0.8	0.75	1	0.8	0.8
October	0.80	0.80	0.8	0.75	1	0.8	0.8
November	0.80	0.80	0.8	0.75	1	0.8	0.8
December	0.80	0.80	0.8	0.75	1	0.8	0.8

1.3.4 *Harvested acres (PctAcresHarvested, %)*

The percentage of acres that are harvested for each type of crop is specified for each month (see Table 22). This input enables the modeler to input information that might describe if the only a portion of the acreage of a given land parcel is harvested in any given month. This is particularly relevant for inputting yields of crops that are assumed to go through more than one crop planting and rotation during the year. For example, if 1/3 of the parcel crop is planted in each of January, February, and March to be harvested 3 months later in April, May, and June, then the PctAcresHarvested = 0.33 for that land parcel and crop choice. For Diversified Agriculture, the value is set to 1 for each month because there are really 4 crops (onions, bananas, cabbage, and lettuce) being modeled as one (= “diversified agriculture”). Because harvested yield = (percent acres harvested)(yield), and yield per month is zero during months with no harvest, the model still correctly calculates yield each month for diversified agriculture.

Table 22. The percentage of acres harvested each month for each crop (0.05 = 1/20, 0.08 = 1/12). Diversified agriculture is modeled slightly differently and has a value of 1 for each month even though there is not a harvest of 100% of the land each month.

	Sugar Cane	Sweet Sorghum	Diversified Ag	Kikuyu Grass	Native	Cassava	Banagrass
January	0.00	0.00	1.00	0.08	0.00	0.08	0.00
February	0.05	0.00	1.00	0.08	0.00	0.08	0.10
March	0.05	0.00	1.00	0.08	0.00	0.08	0.10
April	0.05	0.33	1.00	0.08	0.00	0.08	0.10
May	0.05	0.33	1.00	0.08	0.00	0.08	0.10
June	0.05	0.33	1.00	0.08	0.00	0.08	0.10
July	0.05	0.33	1.00	0.08	0.00	0.08	0.10
August	0.05	0.33	1.00	0.08	0.00	0.08	0.10
September	0.05	0.33	1.00	0.08	0.00	0.08	0.10
October	0.05	0.33	1.00	0.08	0.00	0.08	0.10
November	0.05	0.33	1.00	0.08	0.00	0.08	0.10
December	0.00	0.33	1.00	0.08	0.00	0.08	0.00

1.3.5 Crop yield (CropYield)

The crop yield is for each type of crop is specified for each month (see Table 23). This enables the modeler to input information that might describe if the yield of a crop is different for one month versus another. This is particularly relevant for inputting yields of crops that are assumed to go through more than one crop planting and rotation during the year. The yield is meant to represent the yield *at the time of harvest* and not necessarily an annualized yield. A summary of the yield for each crop is given in subsequent subsections.

Table 23. Yield for each crop if that crop is harvested in a given month (tonnes of fresh weight per acre).

	Sugar Cane	Sweet Sorghum	Diversified Ag	Kikuyu Grass	Native	Cassava*	Banagrass
January	91	0	1	4.3	1	20/30	77
February	91	0	1	4.3	1	20/30	77
March	91	0	1	4.3	1	20/30	77
April	91	9.35	1	4.3	1	20/30	77
May	91	9.35	1	4.3	1	20/30	77
June	91	9.35	1	4.3	1	20/30	77
July	91	18.7	1	4.3	1	20/30	77
August	91	18.7	1	4.3	1	20/30	77
September	91	18.7	1	4.3	1	20/30	77
October	91	9.35	1	4.3	1	20/30	77
November	91	9.35	1	4.3	1	20/30	77
December	91	9.35	1	4.3	1	20/30	77

* Cassava is modeled to have a 'standard' yield of 20 tonnes/acre as well as an 'improved' yield of 30 tonnes/acre.

1.3.5.1 Yield – Sugar Cane

Sugar and total mass:

From sugar yield data provided by HC&S, we calculate a total harvested fresh weight mass of sugar cane. The yield of sugar for a harvest at full yield is approximately 14 short tons/acre for sugar cane grown on a 24-month cycle with the sugar equating to 14% of the fresh weight harvested mass of the crop (see Exhibit G-1 of (CWRM, 2010) and HC&S Fact Sheet (Alexander & Baldwin, 2011)). This sugar yield translates to total crop fresh weight biomass of 100 short tons per acre, or 91 metric tonnes per acre.

Because of the three years of data relating yield and average water delivery for sugar cane production by HC&S on Maui, this model uses those three data points to calculate sugar cane yield per the amount of modeled water applied to the crop (Alexander & Baldwin, 2011)). Given the complex interplay between the timing and quantity of irrigation to biomass and sugar yield, the use of these three data points is highly approximate. A quadratic function describes the yield as a function of "available water/water need for target yield. If the water applied to the crop (via rain and irrigation) is < 110% and > 71% of the water need for an expected normal yield of 91 tonnes/acre (100 short tons/acre) (Equation (1)):

$$\text{Yield (tonnes/acre)} = -263\times(\text{HC\&SAvailableWater/HC\&SWaterNeed})^2 + 584.51\times(\text{HC\&SAvailableWater/HC\&SWaterNeed}) - 228.52 \quad (1)$$

If the water applied to the crop (via rain and irrigation) is > 110% of the water need for an expected normal yield of 91 tonnes/acre (100 short tons/acre) (Equation (2)):

$$\text{Yield (tonnes/acre)} = -263\times(1.1)^2 + 584.51\times(1.1) - 228.52 \quad (2)$$

Molasses:

Using reported values of molasses production, this model assumes that molasses production is one-third of sugar production by mass (Alexander & Baldwin, 2011): 2010: 171,800 tons sugar, 52,800 tons molasses, avg. yield 11.1 tons sugar/acre; 2009: 126,800 tons sugar, 41,700 tons molasses, avg. yield 8.4 tons sugar/acre; 2008: 145,200 tons sugar, 52,231 tons molasses, avg. yield 8.6 tons sugar/acre. These ratios of molasses/sugar is 31%, 33%, and 36% for 2010, 2009, and 2008 respectively.

Fiber:

From communication with Lee Jakeway of HC&S, fiber production is ~ 13%-14% of total biomass harvest. This fiber is 50% moisture by mass per the number reported to the Energy Information Administration data for form EIA-923 that reports biomass consumption for electricity. This model assumes 14% of harvested wet sugar cane is dry fiber and at 50% moisture, 14%/0.5 = 28% is 'wet fiber biomass' that is input into the Puunene Mill for heat and power. For reference, fiber is reported as 13%-14% of cane and cane trash is ~ 14% of cane in Brazil (Seabra et al., 2011).

Electricity from sugar cane

As reported by the EIA data from forms 906/920 for 2009 (forms are now EIA-923), approximately 910-970 kWh/tonne of biomass is generated at the Puunene sugar mill owned by HC&S. As noted above per communication by Lee Jakeway of HC&S, this fiber is approximately 50% moisture by mass. The model uses a value of 950 kWh/tone of 50% moist fiber.

Also, Mr. Lee Jakeway reported in a personal communication that approximately 30% of fiber (as sugar cane bagasse) is used for electricity generation and 70% for heat used in the sugar mill. This model continues to use this 30%:70% assumption for sugar cane.

Ethanol:

From the Hawai'i Bioenergy Master Plan ("Bioenergy Technology" chapter), 163 gallons of ethanol (EtOH) can theoretically be produced from one short ton of sugar, but that practically one tends to produce 141 gallons per short ton (or 155 gallons per metric tonne) (HNEI, 2009). This model uses the conversion factor of 155 gallons EtOH per metric tonne of sugar. Ethanol can also be produced from molasses. The HNEI report notes a practical conversion of 69 gallons EtOH/ton, or 76 gallons EtOH/tonne, the conversion factor used in this model. These assumptions translate to 25 gal EtOH/tonne (23 gal EtOH/ton) compared to the value of 22 gal EtOH/tonne (20 gal EtOH/ton) used in (Tran et al., 2011).

1.3.5.2 Yield – Sweet Sorghum

The data for yield of sweet sorghum in Hawai'i are sparse and highly variable. Thus any estimate of yield of sweet sorghum for Hawaiian conditions is highly uncertain. Researchers at University of Hawaii have done relatively recent trials of growing sweet sorghum (Hashimoto, 2012, Hashimoto et al., 2012)). Further, there are comparative data for mainland and Hawai'i sweet sorghum production for ethanol in (Smith et al., 1987). While the data reported in (Smith et al., 1987) show approximately 44 tonnes/acre of total fresh weight yield, but both the planting and total growing time are not clear.

The sweet sorghum yields assumed in this model are based on communications from Richard Ogoshi and Andy Hashimoto of the University of Hawaii:

> "The experiment on Maui was planted only once in September of 2011, followed by harvests in December, February, May, and September. The total biomass yield for all four harvests was 11.3 dry tons/acre with dry matter at 37%. As Andy [Hashimoto] mentioned, the summer yield was higher than in winter, 4.4 times higher." (May 8, 2013 e-mail correspondence of Richard Ogoshi)

This model raises this value slightly to 12.5 dry tons/acre/year from all three modeled crop cycles for sweet sorghum. This translates to **37.5 fresh weight tonnes** assuming a typical 75% moisture content (Wortmann et al., 2010). As seen in Table 23, the model assumes that 25% of this total yield occurs in the first and third harvests with the remaining 50% occurring during the 2^{nd} (summer) harvest.

The model calculates the quantity of sugar harvested in sweet sorghum using the method of Wortmann (Wortmann et al., 2010). The following equations assume that sugar concentration of sweet sorghum juice is 75% of Brix expressed in g/g sugar juice:

$$\text{conservative sugar yield (CSY)} = (\text{fresh stalk yield (FSY)} - \text{dry stalk yield (DSY)}) \times \text{Brix} \times 0.75$$
$$\text{CSY} = (\text{FSY} - \text{DSY}) \times \text{Brix} \times 0.75$$
$$\text{juice yield (JY), 80\% extracted} = [\text{FSY} - (\text{DSY} - \text{CSY})] \times 0.8$$
$$\text{sugar yield (SY)} = \text{juice yield (JY)} \times \text{Brix} \times 0.75$$

$$\text{SY} = \text{JY} \times \text{Brix} \times (\text{\% of Brix that is sugar concentration of juice})$$
$$\text{SY} = [\text{FSY} - (\text{DSY} - \text{CSY})](\text{\% of juice extracted}) \times \text{Brix} \times (\text{\% of Brix that is sugar concentration of juice})$$
$$\text{SY} = [\text{FSY} - (\text{DSY} - (\text{FSY} - \text{DSY}) \times \text{Brix} \times (\text{\% of Brix that is sugar concentration of juice}))] \times \ldots$$
$$(\text{\% of juice extracted}) \times \text{Brix} \times (\text{\% of Brix that is sugar concentration of juice})$$

The values for the above equation assumed for this study are:

SorghumSugarPercentOfBrix (SSBrix%): **75%**, percentage of Brix that is sugar concentration of juice (Wortmann et al., 2010)

SorghumStalkPercent (SS%): **78%:** percentage of FWY that is stalk. This nominal value is obtained for Hawaii trials from (Smith et al., 1987). Assumed FWY (fresh weight yield) is **37.5 tonnes/acre** (as noted previously in this section).

SorghumBrix (Brix): **0.207 g/g** (value for Hawaii trial from (Smith et al., 1987)), More common value is near 0.15-0.17 g/g for trials in Wortman et al. (2010) for Midwest US sweet sorghum trials

SorghumJuiceExtractEff (SJE%): **80%**: amount of juice that is extracted , or efficiency of sugar juice extraction (Wortman, 2010 assumed ~ 80% as nominal with a range of 80%-100%)

SorghumStalkDryPercent (SSD%): **31.6%** = percentage of stalk that is dry matter (value for Hawaii trials from (Smith et al., 1987)).

These parameter values translate to a sweet sorghum crop in which 25% of the total fresh weight is harvested as dry matter, 10.6% of the harvested stalk (fresh stalk yield is 78% of total fresh weight crop yield) is sugars (2.9 tonnes/acre), and 9.2 tonne/acre of harvested dry mass (DSY = dry stalk yield).

Ethanol and electricity from sweet sorghum

The conversion of sugar from sweet sorghum into ethanol is assumed at the same rate as for sugar cane at 155 gallons of ethanol per tonne of sugar. For estimating gross electricity production from fiber in sweet sorghum, the model assumes the same value as for sugar cane of 950 kWh/tonne of 50% moisture biomass. This electricity conversion value is used to maintain consistency with the sugar cane scenarios. In reality, a new sugar (or ethanol) mill could be constructed to have higher efficiency and high kWh/tonne. I estimate the amount of 50% equivalent moisture fiber from sweet sorghum as in Equation (3):

$$\begin{aligned} &= [\text{dry stalk yield}/(0.5)](\text{Fresh Weight Yield}) \\ &= [\text{SorghumStalkPercent} \times \text{SorghumStalkDryPercent}/0.5](\text{Fresh Weight Yield}) \\ &= [(0.78)(0.316)/(0.5)](37.5 \text{ tonne/acre}) \\ &= 18 \text{ tonne/acre of 50\% moisture equivalent fiber biomass} \end{aligned} \tag{3}$$

1.3.5.3 Yield – Kikuyu grass

Using internal Ulupono Initiative estimates, the model assumes a dry matter yield of 4.3 tonnes/acre/yr (26 lb/acre/day) of forage kikuyu grass.

1.3.5.4 Yield – Cassava

There are no known public data or reports on actual yield data and feasibility for farming cassava on the large scale (23,000 acres) as modeled in this report. This report uses two values for assuming cassava fresh root yields: a nominal value of 20 tonnes /acre and an ‘enhanced’ yield of 30 tonnes/acre as suggested might be possible from data internal to Ulupono Initiative.

The Hawai’i Bioenergy Master Plan reports two yields for cassava (HNEI, 2009): 90 ton/ha for fresh weight of cassava in Thailand (= 36 ton/acre = 33 tonnes/acre) on page 29 of the “Technical Report”, and Table 10 states ranges of 30-51 ton/ha of fresh weight (=11-19 tonnes/acre). Thus 20 tonnes fresh root/acre is taken as the nominal yield.

This fresh weight yield is 50%-70% moisture, and dried cassava chips (still with 12% moisture) are approximately 70% starch by mass (Table 9, pg 29 of “Technical Report” of (HNEI, 2009)). Thus starch is approximately 0.70/(1-0.12) ~ 80% of dry matter harvested from the root. If the root is 50%-70% moisture (30%-50% dry), then the percentage of fresh root that is starch ~ (0.8)(0.3 to 0.5) = 0.24 to 0.4. This report **assumes that cassava starch is 30% of harvested fresh root cassava**.

Ethanol from cassava

The assumed production of ethanol from cassava starch is taken from the theoretical estimates from the Hawaii Bioenergy Master Plan “Technical” chapter, page 18 (HNEI, 2009). The ideal conversion of starch to ethanol, EtOH, is:

$$\begin{aligned} &= (0.5679 \text{ t EtOH/t starch}) / (0.000789 \text{ tonne/L EtOH}) / (3.785 \text{ L/gallon}) \\ &= 190 \text{ gallon EtOH/tonne of starch} \end{aligned} \tag{4}$$

Also stated on page 18 of the “Technical” chapter is that an ideal value of 456 L EtOH/dry short ton of starch translates to 400 L EtOH/dry short ton in practical situations. The amount of ethanol from cassava starch is multiplied by the factor 400/456 = 0.88. Thus, the ethanol yield per tonne of dry cassava starch used in this model is 190 (gal EtOH/tonne starch)(0.88) = **167 gallon ethanol per tonne of starch from cassava**.

Given that dry starch from cassava is modeled as 30% of fresh root yield, the ethanol yield is (0.30 t starch/t fresh root)(167 gal EtOH/t starch) = 50 gallon EtOH/tonne of fresh cassava root.

Electricity from cassava

From data internal to Ulupono Initiative, the 1.82 gross kWh/gallon of ethanol production. The net electricity production is much smaller at 0.15 kWh/gallon of ethanol as most of the electricity generation from cassava stillage, stems, and root peels is needed for internal processing of ethanol.

1.3.5.5 Yield – Banagrass

The modeled banagrass yield is obtained from documents describing crop trials in Hawai'i by researchers and staff at University of Hawai'i and HC&S. From a recent, but undated publication (available March 25, 2013 at: http://infohouse.p2ric.org/ref/35/34186.pdf, (Kinoshita et al., (undated))), banagrass experiments on 4.6 hectares at Hoolehua, Molokai produced (assuming t = metric tonnes):

- "Planted crop" 130 t/ha (fresh weight) at 71.6% moisture, 37.4 t/ha (dry matter) after 7.7 months (assumed t = metric tonnes)
- "Ratoon crop" 125 t/ha (fresh weight) at 64.2 % moisture, 44.6 t/ha (dry matter) after 8 months.

As suggested by discussions with researchers at University of Hawaii and Hawaii Bioenergy, it is likely that banagrass would be planted and rotated for year-round (12-month) production. Thus, the annualized banagrass crop yields from the trial data are 130/(7.7/12) = 200 t/ha and (125)/(8/12) = 190 t/ha for the planted and ratoon crop, respectively. **This model assumes a value of 190 tonnes/ha = 77 tonnes/acre for fresh weight banagrass at 65% moisture**.

This model **uses the ethanol and electricity production assumptions from Table 1-4 of (Black & Veatch, 2010)**. The Black & Veatch study assumes the use of enzymatic hydrolysis as the conversion technology, which would produce ethanol, as well as electricity as a co-product, where each ton of biomass is estimated to produce **80 gallons of ethanol per dry ton of biomass feedstock, plus 2.55 kWh of (assumed as *gross*) electricity, for each dry ton of fiber processed**. As the technology is not yet commercial, it is unclear as to the true yield and time frame for commercialization of cellulosic ethanol production.

1.3.5.6 Diversified agriculture crop yield (DivAgYield)

The diversified agriculture crop yield, DivAgYield, for each type of diversified agriculture crop is specified for each month. Diversified agriculture is meant to generically represent fruits, vegetables, and nuts that are typically grown on relative small plots of land. Thus, if one wants to specify to grow bananas and lettuce, the model does not have separate CropType for bananas and lettuce, but instead the modeler specifies that land parcel to grow CropType = Diversified Ag.

The DivAgYield STELLA element, combined with element DivAgPct, specifies how much of a particular modeled crop (e.g. cabbage) is produced. Just as with CropYield, this element enables the modeler to input information that might describe if the yield of a crop is different for one month versus another and if the crop is not harvested in a given month. This is particularly relevant for inputting yields of crops that are assumed to go through more than one crop planting and rotation during the year. The yield is meant to represent the yield *at the time of harvest* and not an annualized yield.

Slightly different than with CropYield, it is important to put a DivAgYield of zero for crops that are not harvested in a given month and only put the yield for the months of harvest. This is because the element CropYield = 1 for each month of "CropType = Diversified Agriculture" since this is necessary to facilitate diversified agriculture crops that can be modeled with different planting and harvest schedules.

Diversified crop yield data were obtained from the United States Department of Agriculture (USDA) National Agriculture Statistics Service (NASS)[1]. This NASS database reports crop yields per *harvested acre*. The interpretation of these data are that yields are reported each time an acre of land is harvested, even if the same acre of land is harvested more than once. Thus, for pieces of land that harvest more than one crop per year, it is not possible to determine if one particular acre of land is harvested once or multiple times. For example, assume lettuce has a reported yield of 11,000 lb/acre for a given year and that 22,000 lb of lettuce were harvested. The statistics do not tell us if one acre of land was harvested twice or if two acres of land were harvested once. The diversified crop planting cycle was discussed previously in Section 1.3.1.3.

[1] http://www.nass.usda.gov/Statistics_by_State/Hawaii/Publications/Annual_Statistical_Bulletin/

Table 24. Yield during months of harvest for the modeled diversified agricultural crops. Data reported by USDA NASS are in lb/acre (shown in parentheses) and data input to the STELLA model are in tonnes/acre (shown without parentheses).

	Dry Onions	Bananas (ratoon)	Cabbage	Lettuce
January	0	0	(30,000) 13.6	(11,000) 5
February	(13,000) 5.9	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	(30,000) 13.6	(11,000) 5
August	(13,000) 5.9	0	0	0
September	0	(17,000) 7.7	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0

1.3.6 Beef and milk production

The model scenario for grass-fed cattle assumes that half of the cattle are sold for beef and half are used for milk production (STELLA factor "PctBeefCows" = 0.5). Beef and milk production are based upon the quantity of kikuyu (pasture) grass consumed by the cattle. The assumed kikuyu yield is given above in Section 1.3.5.3 and Table 23.

The assumed net quantity of beef production is 89 lbs of beef per tonne of (dry matter) kikuyu grass. Thus, (89 lb beef/t grass)(4.3 t grass/acre/yr) = 383 lb beef/acre/yr. The derivation of the beef production is as follows:

$$\text{Net beef production} = \frac{(\text{gross annual weight gain})(\text{stocking rate})(1-\text{herd support})}{(\text{grass yield})} =$$

$$= \frac{\left(\text{gross weight gain}/\text{time for weight gain}\right)\left(\text{grass yield}/\text{grass consumption}\right)(1-\text{herd support})}{(\text{grass yield})}$$

$$= \frac{\left((\text{finish weight - starting weight})/\text{time for weight gain}\right)\left(\text{grass yield}/\text{grass consumption}\right)(1-\text{herd support})}{(\text{grass yield})}$$

$$= \frac{\left((1{,}150\text{ lb - }400\text{ lb})/1.64\text{ yrs}\right)\left(4.3\text{ tonne grass/acre/yr}/3.45\text{ tonne/head/yr}\right)(1-0.33)}{(4.3\text{ tonne grass/acre/yr})}$$

$$= 89\text{ lb beef/tonne of grass}$$

The assumed net quantity of milk production is 297 gallons of milk per tonne of (dry matter) kikuyu grass. Thus, (297 gallon milk/t grass)(4.3 t grass/acre/yr) = 1,280 gallons milk/acre/yr. This is net milk production that can be sold rather than gross milk production that includes a quantity of milk consumed by the cattle herd for rearing calves. The derivation of the milk production is as follows:

$$\text{Net milk production} = \frac{(\text{gross milk production})(1-\text{herd support})}{(\text{cattle grass consumption})}$$

$$= \frac{(3.13\text{ lb milk/head/ day})(8.576\text{ gal/lb milk})(1-0.20)(365/12\text{ days/month})}{(0.456\text{ tonne grass/head/month})}$$

$$= 297\text{ gallon milk/tonne of grass}$$

1.4 Model Inputs – Energy Module

1.4.1 Energy Flows

1.4.1.1 Electricity for groundwater pumping

The electricity requirements for each groundwater pump serving irrigation are specified in the model element GroundwaterElec and previously documented in Section 1.2.1.2 of this Appendix.

1.5 Model Inputs – Economic Module

1.5.1 Agricultural, electricity, and biofuel prices

The price for sales of agricultural products, electricity, and biofuels are input as an assumed constant value for each product (see Table 25). Also listed is the assumed price for *advanced biofuel* ethanol credits, or RIN: Renewable Identification Number credits, for which all modeled ethanol (from sugar cane, sorghum, and cassava) is assumed to be able to qualify. The RINs are part of the mechanism for the EPA to record compliance with the U.S. Renewable Fuels Standard. Qualifying for the advanced biofuel RIN necessitates a certain reduction in life cycle greenhouse gas (GHG) emissions below that of conventional fuel (e.g. oil-based gasoline), and this report does not calculate life cycle GHG emissions for the fuels modeled. However, it is accepted that sugar cane based ethanol from Brazil does qualify as an advanced biofuel.

Table 25. Product Prices for economic commodities in STELLA model.

STELLA element ($\PRODUCT)	Value & Units	Equation
$\Bananas	0.6 $/lb	--
$\Beef	1.4 $/lb	--
$\Cabbage	0.3 $/lb	--
$\DryOnions	1.25 $/lb	--
$\Ethanol	2.74 $/gallon	--
$\Lettuce	1.9 $/lb	--
$\Milk	2.46 $/gallon	--
$\Molasses	109 $/metric tonne	20% of $\Sugar
$\Sugar	545 $/metric tonne	--
$\kWhRetail	0.34 $/kWh	--
$\kWhWholesale	0.20 $/kWh	60% of $\kWhRetail
$\RINEthanol	0.83 $/gallon EtOH*	--

* The advanced biofuel RIN 30-day average price was 0.83 $/gallon on May 15, 2013.

The cost of electricity for groundwater pumping could span many prices depending upon the specific owner of the groundwater wells and source of power. This model assumes a single price for electricity for groundwater pumping that is a fraction of the retail cost of electricity, "GWElecCostToRetailCostRatio". The factor "GWElecCostToRetailCostRatio" is a constant ratio between 0 and 1 to indicate that the price of electricity paid for groundwater pumping, that could be considered an industrial electricity demand, might be less than the full retail price of electricity.

For all results presented in this report "GWElecCostToRetailCostRatio" = 0.5.

1.5.2 Water prices

The price for assumed water costs for agriculture operations are input as an assumed constant value for each type of agriculture. These water prices are used as nominal values only and do not represent actual surface water prices on Maui.

Table 26. Surface water costs per crop ($/1000 gallons) as modeled.

STELLA element ($\1000galCROP)	Price	Units
$\1000gal1SugarCane	0.1	$/1000 gallons
$\1000gal2Sorghum	0.1	$/1000 gallons
$\1000gal3DivAg	0.1	$/1000 gallons
$\1000gal4Kikuyu	0.1	$/1000 gallons
$\1000gal6Cassava	0.1	$/1000 gallons
$\1000gal7Banagrass	0.1	$/1000 gallons

1.6 Model Inputs – Municipal Water Supply (Modules)

Data input for municipal water supply are assumed fixed for each given month. This is not a major focus of the model, and the level of detail added here is up to the needs of the modeler.

The monthly data for the Maui Department of Water Supply (DWS) are supplied by the DWS on their website (http://co.maui.hi.us/index.aspx?NID=572) under the link sequence form the Maui County main site (http://co.maui.hi.us/): --> "Dept. of Water Supply" --> "Maui Water" --> "Monthly Water Production".

The estimate of the quantity of treated waste water is the ratio of sewage to total DWS water supply: 50% of all DWS surface and groundwater supply is assumed sewage (MauiDWSPercentSewage element in STELLA model). Seventy percent of all waste water is treated by three facilities (Wailuku/Kahului, Lahaina, and Kihei) where the other 30% of wastewater is assumed to go to "other" facilities that are private or to cesspools and septic systems (see page 41-44 of (Grubert, 2011)).

Table 27. Municipal and private water supply quantities and electricity needs for pumping and distribution. Most data (aside from 2012-2013 DWS monthly water supplies) are as collected from the Master thesis of Emily Grubert (Grubert, 2011). GW = groundwater, surface = surface water, WWRF = waste water reclamation facility, MG = millions of gallons, kWh = kilo-watt hour

	Maui Municipal Water Supply Name	**Supply Quantity (MGD/month)**	**Electricity for supply (kWh/MG)**	**Electricity for distribution (kWh/MG)**
Groundwater	DWS, Upcountry GW	1.2	7,000	1,300
	DWS, East Maui GW	0.34	0	1,300
	DWS, Iao GW	13 to 18.4	2,200*	1,300
	DWS, Waihee GW	3.4 to 4.7	2,200*	1,300
	DWS, Kepaniwai GW	0.8	2,200*	1,300
	DWS, Iao tunnel, GW	1.4	2,200*	1,300
	DWS, Maui Lani, GW	1.1	2,200*	1,300
	Private, West Maui, GW	4	7,000	--
	Private, East Maui, GW	0.2	0	--
	Private, Central Maui, GW	1.2	2,200*	--
	Private, Upcountry, GW	0.1	2,200*	--
Surface Water	DWS, Central Maui, Surface	0.5 to 1.1	--	1,400
	DWS, Upcountry, Surface	5.5 to 8.6	--	1,400
	DWS, West Maui, Surface	2.8 to 3.6	--	1,400

* Value of 2,200 kWh/MG for groundwater pumping is a general average values used for groundwater pumping (Grubert, 2011).

Different Maui wastewater systems treat water to both R1 (tertiary treated recycled water that can be used without restrictions) and R2 (disinfected secondary treated recycled water with restrictions on uses and applications) standards. Fifty percent of wastewater from Lahaina and Kihei is assumed treated to R1 standard using ultraviolet disinfection technology at 340 kWh/MG of water treated (Grubert, 2011). The Wailuku-Kahului Wastewater Reclamation Facility is assumed to treat water to R2 standard.

Table 28. Flow quantities and energy for treatment of waste water and reclaimed water.

	Maui Municipal Water Supply Name	Supply Quantity (MGD/month)	Electricity for treatment (kWh/MG)	Electricity for distribution (kWh/MG)
Wastewater	DWS, Wastewater	50% of DWS surface and groundwater	2,900	--
	Private, Wastewater	100% of Private groundwater	2,900	--
Reclaimed Water	DWS, Wailuku-Kahului, WWRF	70% of 7/15 of DWS waste water	--*	--
	DWS, Lahaina, WWRF	70% of 4/15 of DWS waste water	340**	980
	DWS, Kihei, WWRF	70% of 4/15 of DWS waste water	340**	980
	DWS, Other, WWRF	30% of DWS waste water	--	--

* Electricity for R2 treatment assumed included in DWS water treatment electricity.
** 50% of wastewater from Lahaina and Kihei is assumed treated to R1 standard using ultraviolet disinfection technology at 340 kWh/MG of water treated.

Grubert's thesis estimates the electricity for distributing R1 water from Lahaina and Kihei treatment facilities (Grubert, 2011):

> "Estimates for the energy intensity of distributing reclaimed water are based on infrastructure at Kihei Wastewater Reclamation Facility, where an average 1.6 to 2.0 million gallons of R-1 water (the highest quality nonpotable water class[104]) are distributed daily by two 1,500 gallon per minute pumps[105]. Assuming typical values for end user pressure of 60 pounds per square inch (psi) and pump efficiencies of 80 percent, the equation (5) ... where a pump efficiency of 80%, suggests that distributing Kihei's reclaimed water requires about 980 kWh per million gallons. This value is about 40 percent higher than distribution electricity needs at HC&S (Table 3). Given that Kihei uses an elevated storage tank to provide water pressure[107], the estimate of 980 kWh per million gallons for distributing reclaimed water is probably conservative, as electricity intensity is directly proportional to pressure by (5). For example, assuming that pumps only need to supply 30 psi rather than 60 psi reduces the total electricity demand estimate from 980 kWh to 490 kWh per million gallons. Some additional electricity is required to keep the pressurizing tank full."

2. Model Outputs

The model calculates many output values of general interest, and many necessary intermediate values that are not of general interest. For a full description of outputs, see the additional documentation that describes the STELLA model in detail: *Description of Model for Investigating Land, Water, Energy, and Food Scenarios in Hawai'i*.

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