{ TC "'CHAPTER 6: SIMULATION RESULTS'" \L 1 }CHAPTER SIX

SIMULATION RESULTS

In the last chapter, we have discussed in detail the new PV pumping system model and UW-PUMP program and showed how the long-term performance of PV pumping system can be estimated in terms of the design parameters of components.

This chapter analyzes monthly and annual performance estimates of the PVPS made with the new model in three sections. In section 6.1, the verification has been made between the UW-PUMP EES version and the TRNSYS program. In section 6.2, different statistical evaluations of UW-PUMP's results are compared to the PVCAD program which is used at SolarJack. In section 6.3, a case study shows the performance of 3 kinds of PV pumping systems, i.e. directly coupled system, a system with MPPT and a system with variable array configuration of PV modules simulated by using the UW-PUMP EES.

6.1 Validation of the UW-PUMP EES{ TC "6.1 Validation of the UW-PUMP EES" \l 2 }

The primary use of the UW-PUMP EES is for predicting the long-term water output of PV pumping system. Before we use the UW-PUMP EES, some comparison should be conducted to evaluate the accuracy of the UW-PUMP EES.

The PV model, the pump model and the MPPT model have been verified in chapter 2, chapter 3 and chapter 4 respectably. This section presents comparison between the TRNSYS and the UW-PUMP EES. Here the TRNSYS use the same PV model and pump model. The comparison for monthly and annual water output are included. Throughout the following analysis, all statistics for the UW-PUMP EES will be calculated relative to the TRNSYS as a dimensionless RMS. To assess whether the UW-PUMP is consistent with the TRNSYS, 6 cases were run with each of two programs. The 6 cases included 2 water heads (92 feet and 162 feet) and 3 cities, (Albuquerque, Madison and Seattle), that cover very different annual radiation cases in U.S. Two results from each case are used in this evaluation: monthly and annual provided water output.

The components of PV pumping system is shown as following. The PV array includes 8 modules in series, 3 modules in parallel. The type of module is Simens M75. The detail PV array data can be found in the Appendix C. Those PV modules are installed at tilt angle as latitude and azimuth is zero. The type of pump is the SolarJack SCS5.7-160. The water head are 93 feet and 162 feet. The weather data used in TRNSYS program is the TMY data. The weather data of 3 cities is used in the comparison. i.e. Albuquerque, New Mexico; Madison, Wisconsin; Seattle, Washington. The UW-PUMP EES uses the generated weather data. The average monthly temperature is used in the UW-PUMP EES because of the lack of measured temperature data. The simulation was conducted over a period of one year.

Table 6.1 summarizes the relative difference between the monthly and annual pumped water by direct-coupled pumping system predicted by the UW-PUMP EES and the TRNSYS. Those results are also broken down by location as shown in Figure 6.1 to Figure 6.3.

Table 6.1 The summarized results of pumped water at 3 cities at head as 92 feet. The PV array 8 in series and 3 in parallel. The pump is SCS5.7-160. The unit is gallon.**{** TC "Table 6.1 The summarized results of pumped water at 3 cities at head as 92 feet. The PV array 8 in series and 3 in parallel. The pump is SCS5.7-160. The unit is gallon." \l 8 **}**

Month	Albuquerque		Madison		Seattle	
	TRNSYS	EES	TRNSYS	EES	TRNSYS	EES
Jan	103474	101842	55483	50538	13629	14571
Feb	115169	122783	64280	62490	26183	31040
Mar	140673	138076	99243	94678	64653	58893
Apr	157722	155540	83711.6	80392	74149	70006
May	162515	159621	96596.5	95151	91864	88049
Jun	152189	157040	98292	99318	88898	85778
Jul	153708	158956	108382	101474	116556	120933
Aug	155716	153544	114015	115797	105634	94149
Sep	147723	148407	97703	88059	82239	75682
Oct	149914	148407	74105	76716	49071	48731
Nov	121831	113925	48832	45920	18337	23832
Dec	107741	100079	36131	33092	12425	13572
	RMS%	3.01650	RMS%	4.25377	RMS%	6.53091

The Figure 6.1 to Figure 6.3 show how the two models compare over all cases for one year simulation are intended to show the sensitivity of various performance measure to the location and system components. It has shown that the annual RMS difference of 3.01% for Albuquerque, 4.25% for Madison, and 6.5% for Seattle, compared with results of TRNSTS program. The difference is likely due to: (1) The TRNSYS uses the TMY weather data. The UW-PUMP EES uses "10 typical days" to represent the monthly radiation and average monthly temperature. (2) The monthly average clearness index for Seattle in January very low (0.3 about), compared with Albuquerque that clearness index is 0.62 for the January.

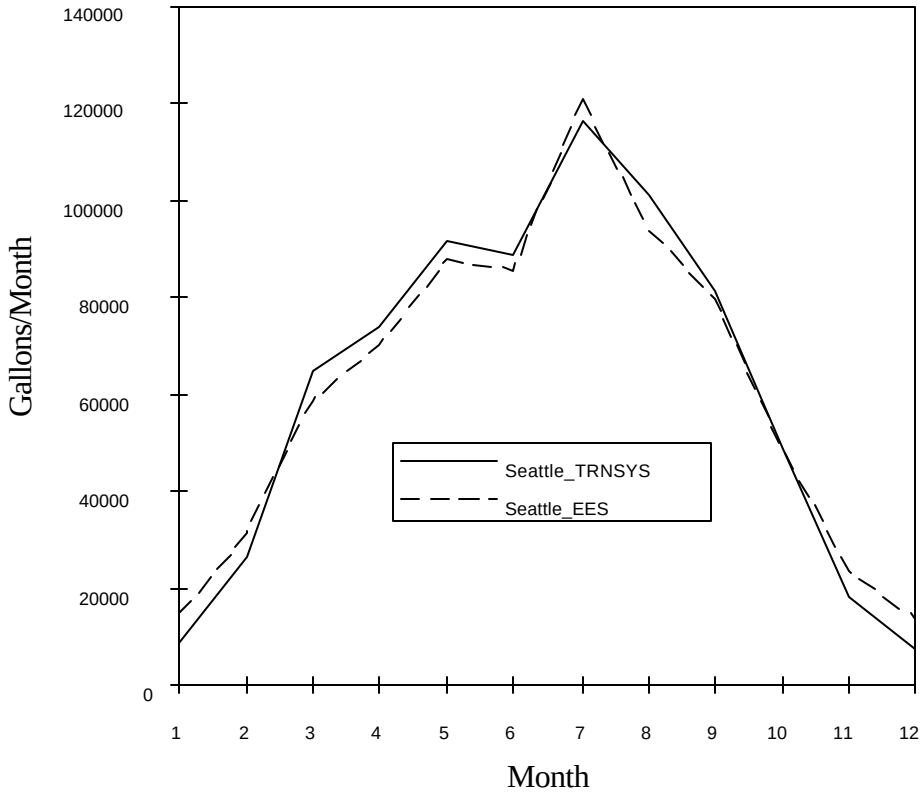


Figure 6.1 The pumped water in Seattle simulated by EES and TRNSYS program{ TC "Figure 6.1 The pumped water in Seattle simulated by EES and TRNSYS program" \l 6 }

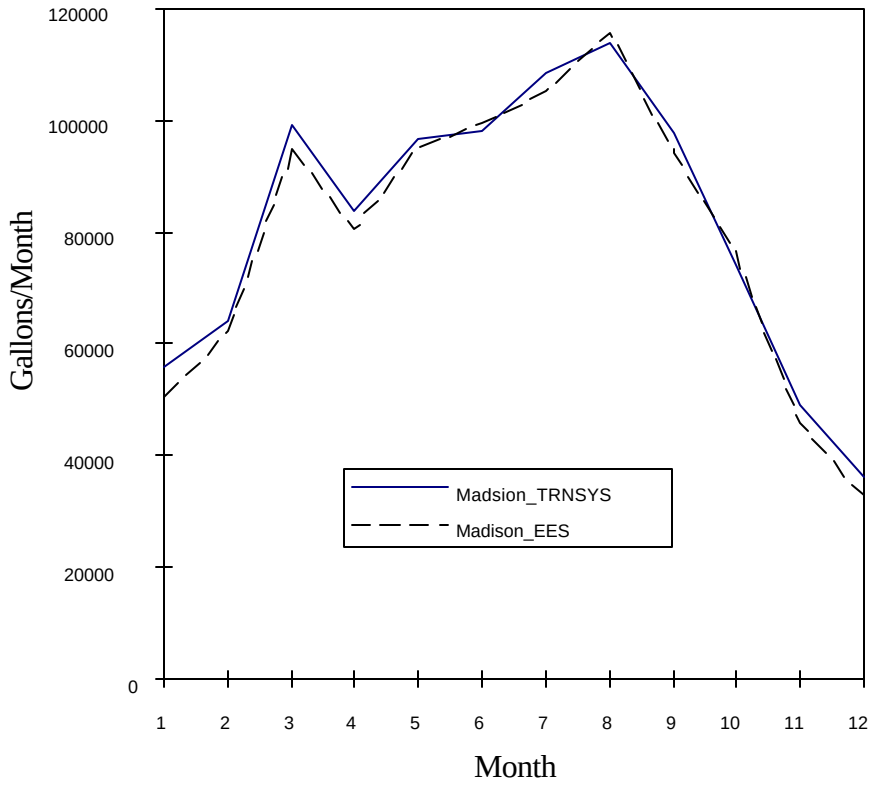


Figure 6.2 The pumped water at Madison simulated by EES and TRNSYS program{ TC "Figure 6.2 The pumped water at Madison simulated by EES and TRNSYS program" \l 6 }

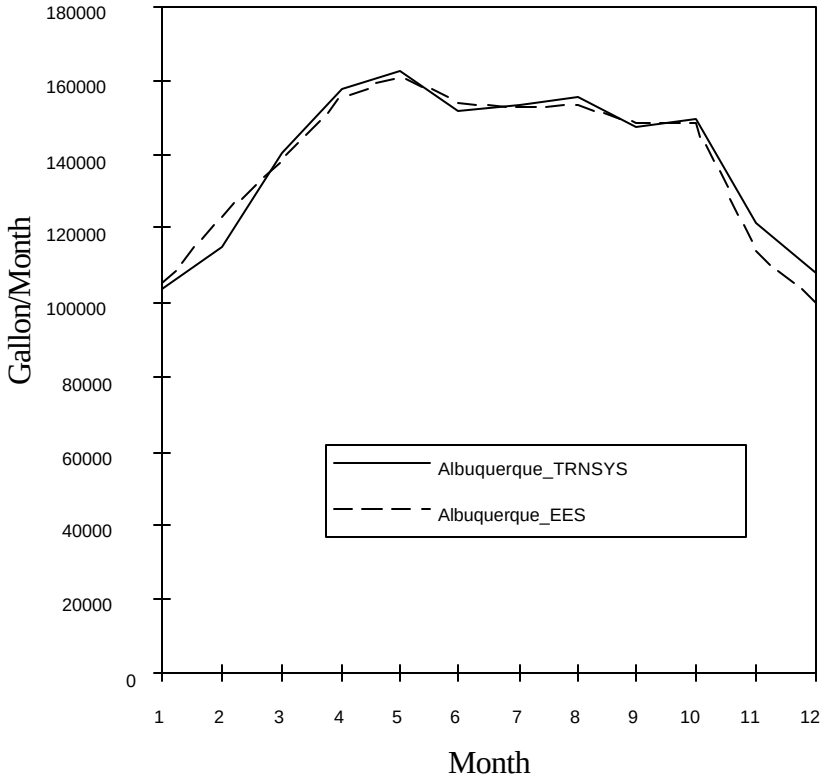


Figure 6.3 The pumped water at Albuquerque simulated by EES and TRNSYS program{ TC "Figure 6.3 The pumped water at Albuquerque simulated by EES and TRNSYS program" \l 6 }

6.2 The Comparison Between the PVCAD and UW-PUMP{ TC "6.2 The Comparison Between the PVCAD and UW-PUMP" \l 2 }

To illustrate the method, the next step is to examine the UW-PUMP EES program with the PVCAD program. The PVCAD is used at SolarJack for simulating the performance of the PV pumping system.The SolarJack has provided a set of simulation results of a typical PVPS by using the PVCAD. The simulation results include the detail operating point of PV pumping system in hourly radiation basisand temperature. This is a chance to evaluate the performance of UW-PUMP EES with manufacturer's program.

The components of the PVPS used in their simulation is as following. The type of pump is one SolarJack SCS18-160. The PV array consists 12 Kyocera KC-80 modules, 6 in series and 2 in parallel. The water head is 125 feet. The cities are Madison, Seattle, Albuquerque.

The source of uncertainty in UW-PUMP and PVCAD are the component models of PVPS and weather data. Therefore in the first step, a simulation has been conducted to compare the difference of the component models used in the PVCAD and the UW-PUMP EES. The performance comparison of the PVCAD and the UW-PUMP EES under same radiation and temperature has been made and the results are shown in table 6.2.

The data of PVCAD section is provided by SolarJack. For the same radiation and temperature used in the PVCAD, the simulation results from the UW-PUMP is shown in the UW-PUMP section. The results from the UW-pump is very close to the results from the PVCAD. The RMS difference of two software is less 0.6%. This means these two programs have a good agreement on the calculation of operating point of the PV pumping system. It also

indicates that the new developed and improved components models use in the UW-PUMP are accurate.

Table 6.2 The comparison of model performance of PVCAD and UW-PUMP{ TC "Table 6.2 The comparison of model performance of PVCAD and UW-PUMP" \l 8 }

UW-PUMP EES					
RADIATION (W/M^2)	T_CELL	FLOW(GPM)	I_max	I_pump	V_pump
260	42.9	0	2.321	2.622	50.5
520	61	5.062	4.712	5.139	81.19
730	76.2	12.01	6.67	6.637	96.49
880	87.7	14.91	7.7	7.3	103.6
910	91.8	15.44	8.1	7.4	104.9
910	93.6	15.56	8.12	7.604	105.2
880	93.2	15.13	8.124	7.486	104.2
730	85.3	11.6	6.34	6.54	94.6
520	73.3	5.12	4.761	4.8	81.87
260	57	0	2.354	2.668	51.12
PVCAD					
RADIATION (W/M^2)	T_CELL	FLOW(GPM)	I_max	I_pump	V_pump
260	42.9	0	2.3	2.2	47.9
520	61	5.1	4.7	4.8	82.7
730	76.2	11.6	6.5	6.46	95
880	87.7	14.55	7.9	7.26	101.5
910	91.8	14.31	8.2	7.19	100.8
910	93.6	15.38	8.2	7.51	103.7
880	93.2	14.1	7.9	7.12	100.3
730	85.3	10.72	6.6	6.23	93.1
520	73.3	3.98	4.7	4.52	80.8
260	57	0	2.3	2.38	51.2
Results	RMS %	0.611292	0.427183	0.697899	0.117957

Now in the second step, the amount of monthly and annual pumped water can be evaluated by using the UW-PUMP EES and the TRNSYS. The simulation results are shown in Figure 6.4 to Figure 6.6. The results shows that the UW-pump EES version results are more close to the TRNSYS results which used the TMY weather data. The results from the PVCAD also are plotted in the Figure 6.4 to Figure 6.6. Those data are provided by SolarJack. The weather data used in the PVCAD is one average day radiation and temperature for each month.

The RMS difference of simulation results from three program shows that the results from the UW-PUMP EES is more accurate than those from the PVCAD. The results of the monthly pumped water at Albuquerque calculated by using the PVCAD is reasonable because the K_T distribution for each month is very high (0.6 to 0.8). The simulation results for the Madison and Seattle are far off from the TRNSYS because the K_T distribution of Madison and Seattle changes from the very low (0.3) to very high (0.8). The PVCAD only use the average day as the weather data therefore it leads to the large error for each month.

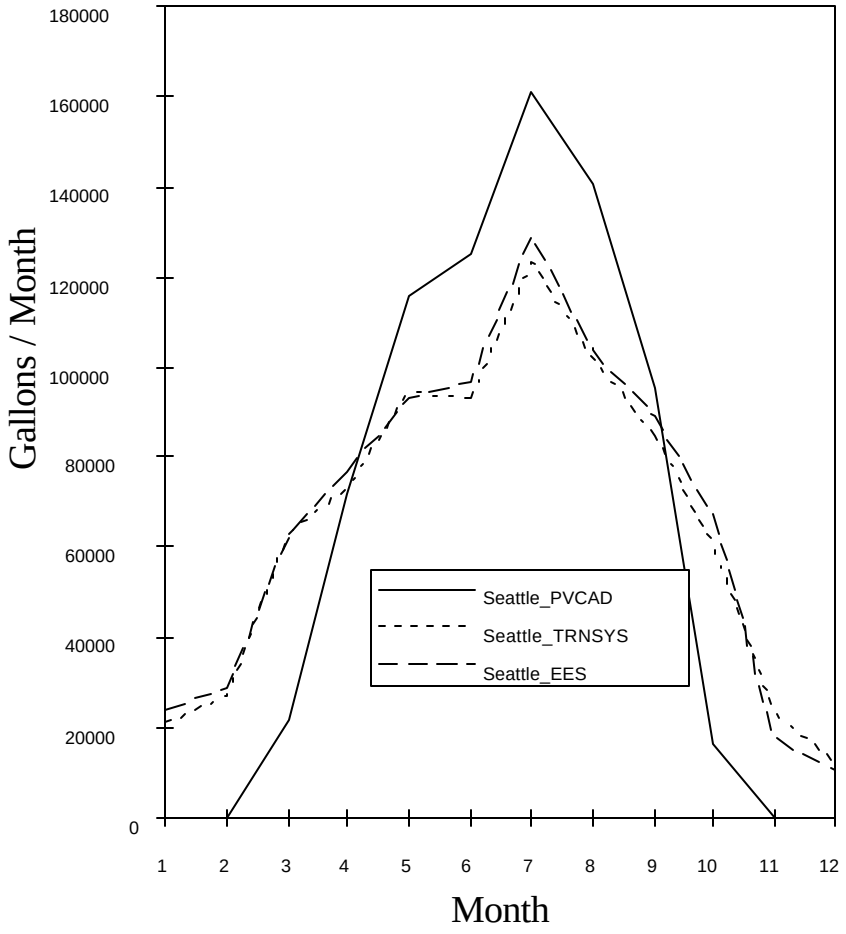


Figure 6.4 The comparison of UW-TRNSYS, EES and PVCAD, Seattle{ TC "Figure 6.4 The comparison of UW-TRNSYS, EES and PVCAD, Seattle" \l 6 }

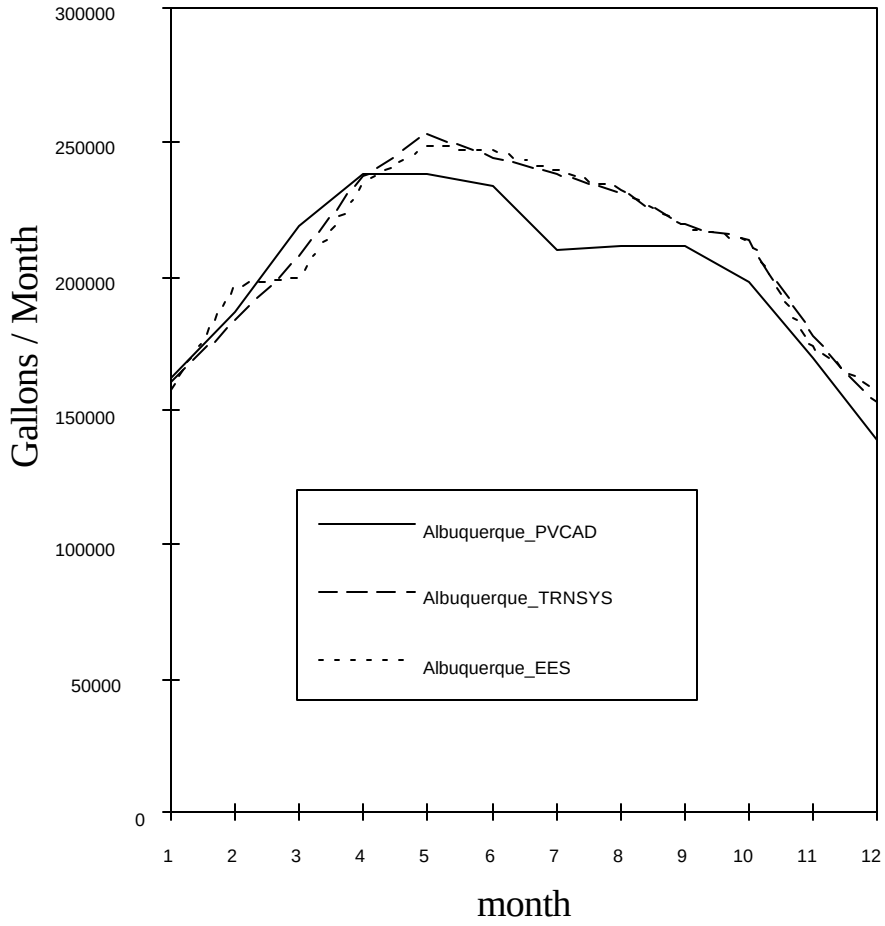


Figure 6.5 The comparison of UW-TRNSYS, EES and PVCAD, Albuquerque{ TC "Figure 6.5 The comparison of UW-TRNSYS, EES and PVCAD, Albuquerque" \l 6 }

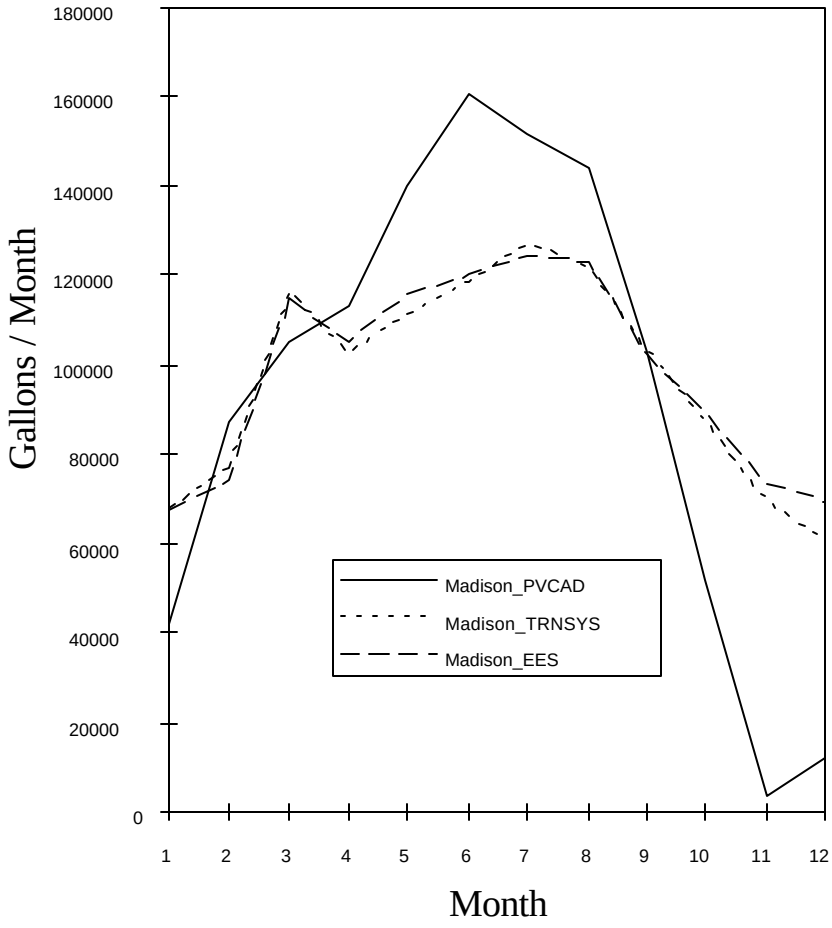


Figure 6.6 The comparison of UW-TRNSYS, EES and PVCAD, Madison{ TC "Figure 6.6 The comparison of UW-TRNSYS, EES and PVCAD, Madison" \l 6 }

Table 6.3 The comparison of amount of monthly and annual pumped water at 3 cities by using PVCAD, UW-PUMP and TRNSYS **{** TC "Table 6.3 The comparison of amount of monthly and annual pumped water at 3 cities by using PVCAD, UW-PUMP and TRNSYS " \l 8 **}**

	Albuquerque_PVCAD	Albuquerque_EES	Albuquerqu_TRNSYS
Jan	161490	157802	161277
Feb	187080	197121	183374
Mar	218430	199267	207539
Apr	238020	234312	237241
May	238350	248275	253406
Jun	233550	247728	244071
Jul	209520	239021	238622
Aug	211860	232883	231544
Sep	211950	218939	219111
Oct	197430	213826	213572
Nov	170100	173842	177695
Dec	139320	156483	153356
total	2417100	2519499	2520808.6
annual RMS%	0.1575488	0.03069184	

	Madison_PVCAD	Madison_EES	Madison_TRNSYS
Jan	41850	67324	68074
Feb	87150	74281	77304
Mar	105000	114842	116416
Apr	113250	105032	102800
May	140160	116213	111200
Jun	160800	119939	118261
Jul	151890	124299	127158
Aug	143910	123042	121890
Sep	102900	102123	103502
Oct	52290	89123	87062
Nov	3720	73439	69618
Dec	11910	69219	61046
total	1114830	1178876	1164329.5
annual RMS%	0.2692315	0.04333613	

	Seattle_PVCAD	Seattle_EES	Seattle_TRNSYS
Jan	0	24127	21289
Feb	0	28912	27381
Mar	21600	62688	63029
Apr	72240	76632	73227
May	115590	93091	94688
Jun	125040	96526	93197
Jul	161070	128977	123111
Aug	140370	104093	102089
Sep	95580	88868	84732
Oct	16800	67571	60613
Nov	0	17808	23778
Dec	0	10434	12370
total	748290	799727	779503.67

annual RMS%	0.107082	0.06548441	

6.3 Case Study{ TC "6.3 Case Study" \l 2 }

To illustrate the application of the UW-PUMP EES, a case study has been conducted. The system is as following. The type of the pump is SolarJack 5.7-160. The type of the PV module is Simens M75. The PV modules are 8 in series and 3 in parallel. The monthly variation in gallons of water pumped in Albuquerque, Madison, and Seattle with two heads (92 feet and 162 feet) is shown in Figure 6.7 to Figure 6.9.

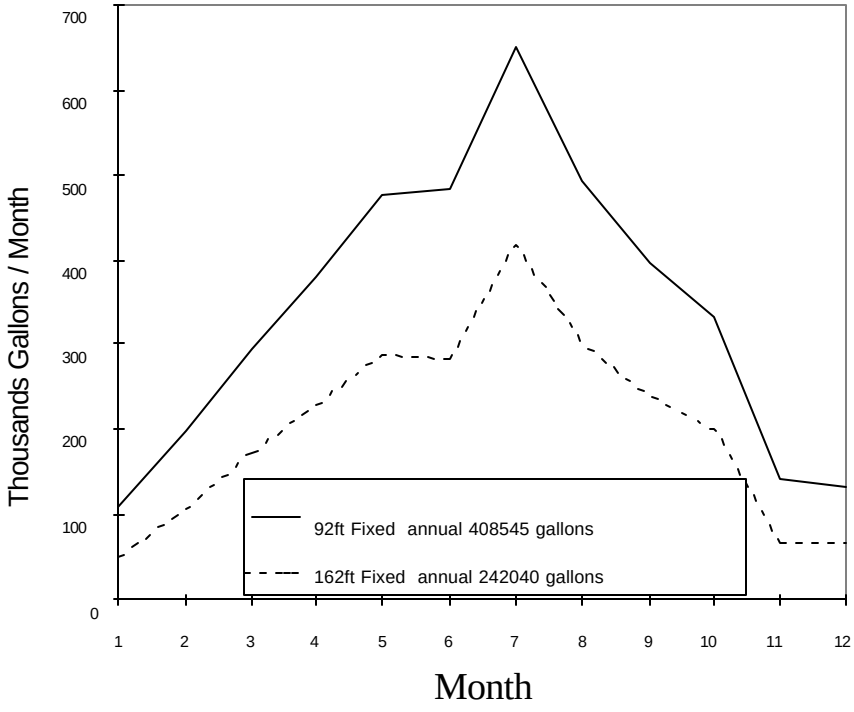


Figure 6.7 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Seattle{ TC "Figure 6.7 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Seattle" \l 6 }

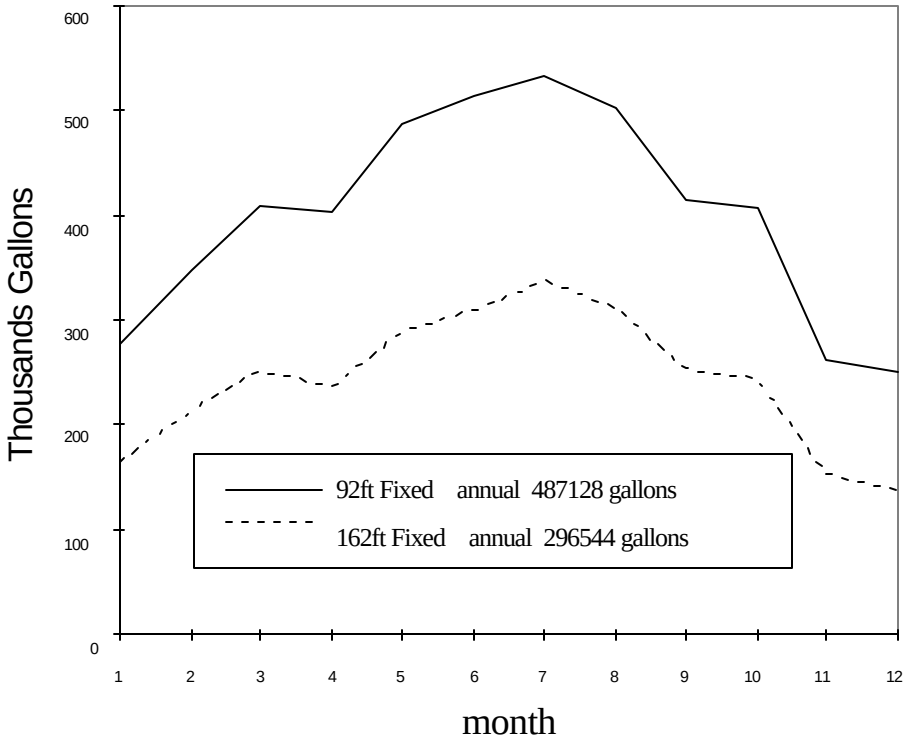


Figure 6.8 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Madison{ TC "Figure 6.8 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Madison" \l 6 }

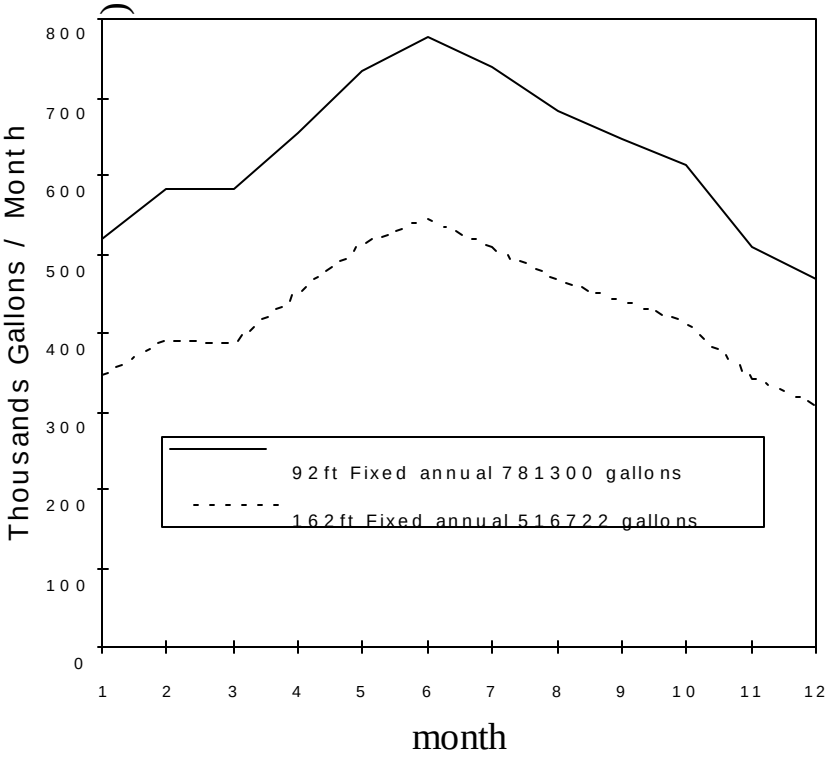


Figure 6.9 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Albuquerque{ TC "Figure 6.9 Design example by UW-PUMP EES. Pumped water at two heads of 92 feet and 162 feet with fixed configuration of PV array. Albuquerque" \l 6 }

The UW-PUMP EES also can simulate different PV pumping systems . The Figure 6.10 to Figure 6.12 show the amount water pumped by 3 PV pumping systems. These three systems use same number of PV modules and pump. One system is the fixed configuration PV array. One system uses an MPPT. The type MPPT is the SolarJack PCB 8-120 boost MPPT. The third system uses the variable configuration of PV array. The configuration of the PV array under different weather condition is calculated by the UW-PUMP EES and automatically is changed during the simulation process. The results show that for a well designed directly coupled PV pumping system, the MPPT and variable configuration of PV array are not significant effective methods.

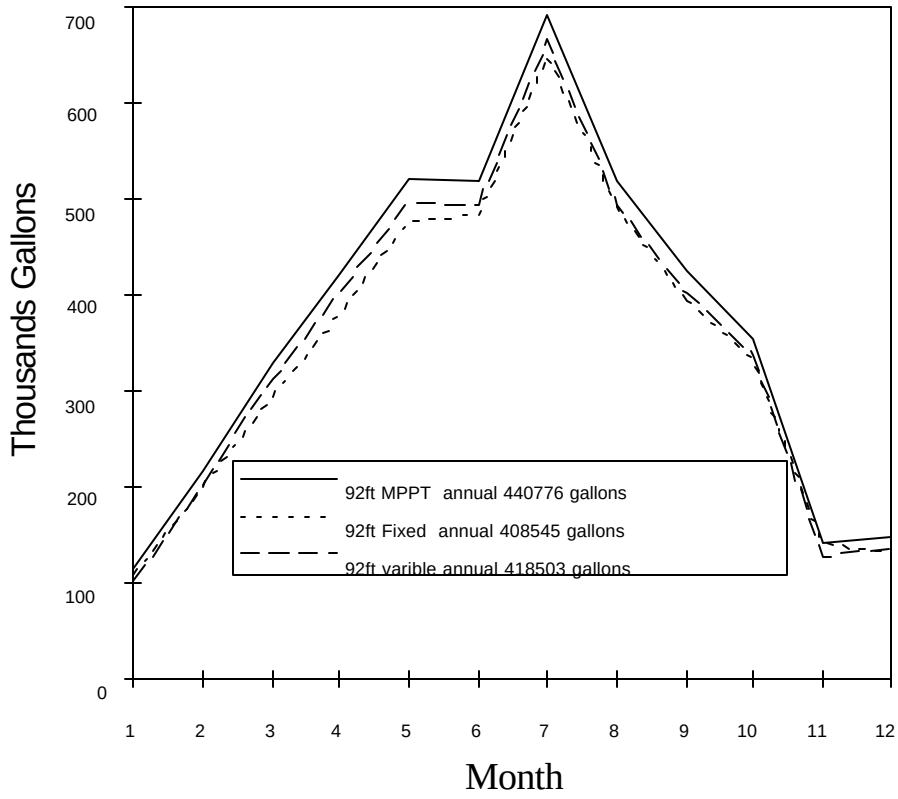


Figure 6.10 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Seattle{ TC "Figure 6.10 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Seattle" \l 6 }

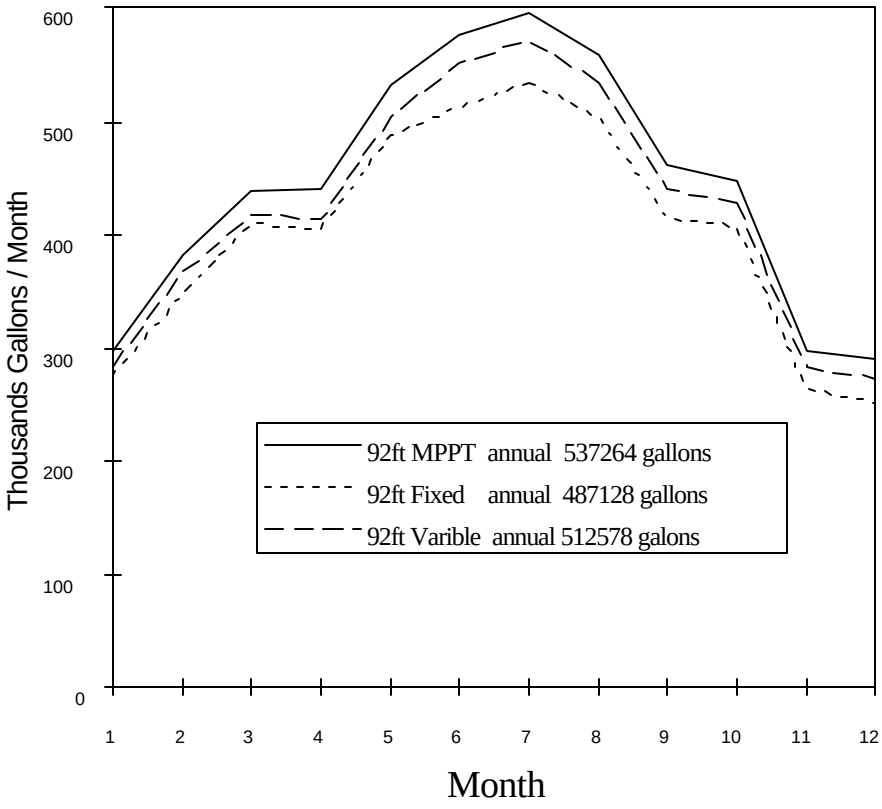
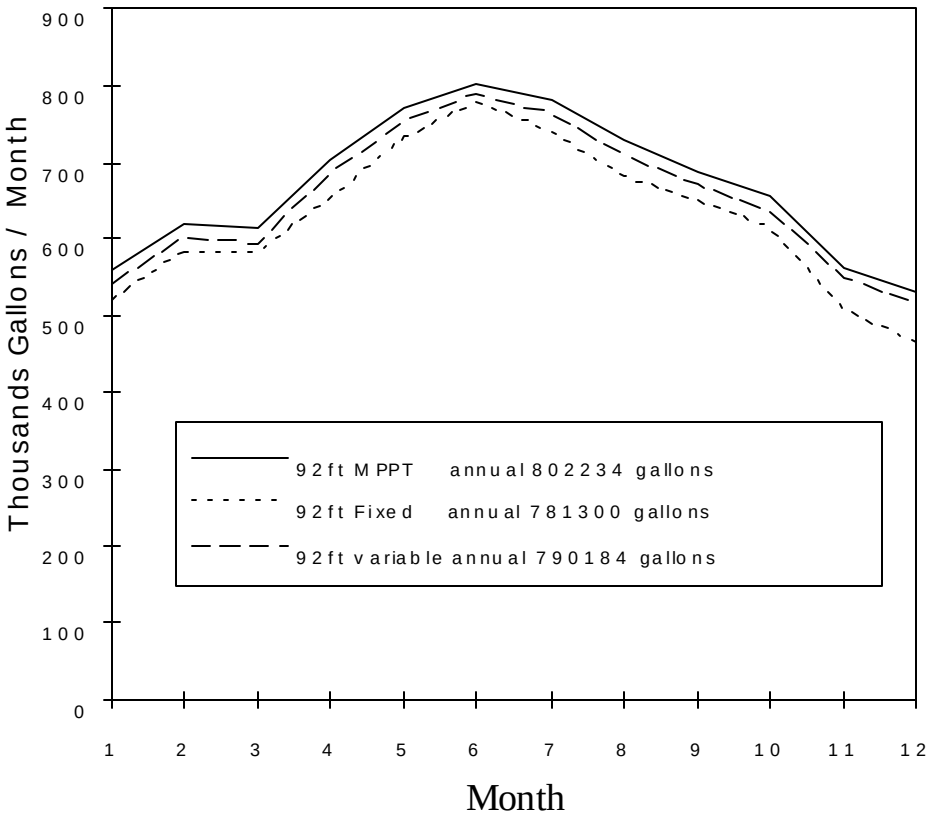


Figure 6.11 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Madison{ TC "Figure 6.11 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Madison" \l 6 }



igure 6.12 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Albuquerque**{** TC "Figure 6.12 Design example by UW-PUMP EES. Pumped water at a head of 92 feet and with MPPT, fixed configuration of PV array, and variable PV array. Albuquerque" \l 6 **}**

Those plots can help users to understand the performance of PV pumping system and optimize the system. The difference of amount of pumped water from the different system will provide an indicative factor to decide which system is the best one.