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Project Title: Design of a Photovoltaic Power System to Pump Surface Water to an Irrigation Reservoir

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Abstract

Groundwater sources in Eastern Arkansas are depleting due to overuse. This project provides a design for solar-powered surface water irrigation pumping for the University of Arkansas Northeast Rice Research & Extension Center (NERREC). The goal of this project was to limit the use of the Mississippi River Valley Alluvial Aquifer (MRVAA), as well as limit the carbon emissions from diesel pumps. To do this, a crop water demand and irrigation schedule were determined. A photovoltaic (PV) array was sized and arranged to meet the client's need, and pump, motor and variable frequency drive were recommended to complete the system. The final design included a PV array (monocrystalline, 320 watt, Heliene 60^{MBLK} modules, quantity 72) mounted at a fixed-tilt of 20^{o}. The array was connected to a variable frequency drive, Nidec HOLOSHAFT WP1 motor (20 HP), and Cascade 12 MFC pump. The system model predicted that all of the required irrigation water could be provided by the surface water pump, with all energy provided from an off-grid solar array.

Keywords

Irrigation reservoir, Photovoltaics, Pump/motor system, Variable frequency drive

Acknowledgments

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INTRODUCTION

Traditionally farmers, especially in the eastern Arkansas area, utilize groundwater to irrigate their crops. The groundwater in eastern Arkansas is pulled from the Mississippi River Valley Alluvial Aquifer, one of the largest aquifers in the United States. Using this source of water to irrigate crops can be reliable when a well is drilled. However, the high use of this aquifer has caused withdrawals to exceed the recharge rate by nearly double (Reba et al., 2017). If this continues, the water supply could be depleted, with increasing depth to water, greater pumping energy required, and excessive carbon emissions. An alternative to using groundwater is pumping nearby surface water into an irrigation reservoir. It is common for farms to utilize a diesel-powered pump to transfer this groundwater to a reservoir. To reduce carbon emissions while preserving the water levels in the Mississippi River Valley Alluvial Aquifer (MRVAA), solar energy could be used to power a pump motor system to carry surface water to an irrigation reservoir.

PROBLEM STATEMENT

A promising location to implement solar pumping is the University of Arkansas Northeast Rice Research & Extension Center (NERREC) that is being constructed in Harrisburg, Arkansas for agricultural research. The 450-acre farm has half of its area devoted to growing rice and the other half for soybeans. A bayou runs down the west side of the farm. See Figure 1. Surface water from the bayou could be pumped into an existing reservoir. There is a possibility that the reservoir could hold enough water to irrigate all 450 acres. This could be a good site for solar pumping because NERREC was already considering solar energy for pumping and there is an open area for photovoltaic (PV) panels. At present, there is no electric service near the reservoir, so if the client did not want to use diesel fuel, an off-grid solar array could be a solution. The problem this project addressed was pumping enough water into the reservoir to irrigate for the entire growing season with solar energy being the only energy source used.

DESIGN GOALS

The main function of the system is to transform raw solar energy into usable energy to pump water from a nearby bayou to an irrigation reservoir. The goal was to find the most efficient, cost-effective, and environmentally-conscious way to do this. The team's approach was to size the lowest cost and most efficient photovoltaic array and pump system based on accurate water demand for the site.

The client expressed their desire for a system that was economical, easy to operate, reduced the farm's carbon emissions, and reduced the need for groundwater pumping. The team considered these as the design objectives. Furthermore, the client also expressed certain requirements. The system must be capable of irrigating all of the cropping area on the farm. The site is fixed and subject to local rainfall, climate, crop growth and surface water conditions. These were the design constraints.

The design team, a group of undergraduate students in biological engineering at the University of Arkansas, were motivated to do this project because of the impact it could have in shifting the region from fossil fuel-based ground water pumping, to more sustainable operations that utilize abundant surface water and solar energy.

Figure 1: Plan view of NERREC from Burcham (2021) showing the irrigation reservoir and the bayou which surface water could be pumped from.

The system needs to meet the estimated water demands of the farm by filling the 350 ac-ft reservoir that is already in place. This volume was found by developing a stage storage table assuming the reservoir is has trapezoidal cross-sections. It was also assumed that the longest bottom width of the reservoir was 1000 feet, the top width was 1800 feet, the side-slope was 2:1, and 1.5 feet of freeboard was needed. A stage-storage table can be found in **Appendix A**.

Such reservoirs are normally allowed to drain from October through December to reduce wind-induced erosion during the off-season. Since there is no grid electricity at the reservoir, an envisioned photovoltaic (PV) system will have to operate completely off-grid. Energy storage (i.e., batteries) was considered but was too expensive. For simplicity, it was decided that the system would only pump when the solar energy was sufficient at any moment to power the pump. Most large irrigation pumps typically operate on AC power; however, solar panels generate DC power. An inverter would typically be required. A variable frequency drive (VFD) was envisioned as a way to convert the solar energy from DC to AC and to allow varying motor speed.With a reduced speed, the pump could still operate during periods where solar power is marginal (mornings and afternoons, partly cloudy days). VFDs have specific design considerations including input DC voltage, output voltage and frequency, and the need for invertor-duty motors. Pump flow rates are dependent upon shaft speed, and variable-speed motors require a minimum power to run and their efficiency changes with shaft rotational speed. Finding an optimal configuration was recognized as a difficult challenge.

Review of Related Work

Solar pumping is typically implemented for small-scale systems, but this project is large-scale. Although larger applications are not common, there is still related work that helped with this design process. Campana et al. (2013) described a dynamic model of a photovoltaic (PV) pumping system. Their method of designing a solar pumping system started with the determination of crop water demand using the FAO Penman-Monteith method. Solar radiation data was collected from WINSUN, which is software based on the transient system simulation tool (Campana et al., 2013). The effect of temperature was estimated separately through a MATLAB script. The motor and pump system was sized using a combination of governing equations for electric motors, affinity laws, and hydraulic power. The authors evaluated both alternating current (AC) and direct current (DC) pumps and both fixed and two-axis tracking PV arrays. This model was helpful because many different types of designs were analyzed and reported.

Engineering Design Process

There were three main tasks within the design of this solar pumping system:

- Determining crop water demand for 225 acres of soybeans and 225 acres of rice.
- Analyzing solar radiation data to find the best average tilt angle.
- Sizing a pump based on variable frequency pump curves, dynamic water demand, and available solar energy that varies seasonally (by day of the year) and diurnally (by the hour of the day).

An optimal tilt angle was identified because a fixed panel (rather than single-axis or dual axis tracking) system was chosen to lower costs and simplify maintenance. For this project, solar pumping scenarios were analyzed on the months that pumping would occur (January through July). Several different pumps were considered (8 MF, 10 MF, and 12 MFC, Cascade Pump Co., Santa Fe Springs, CA). These pumps were chosen based on the client's experience and preference. Once a particular pump was chosen, a parts list was created and an economic analysis was completed for a full system design. Each of the three tasks are described in more detail below.

CROP IRRIGATION DEMAND

The first step in sizing the system was finding the water demand. There are many methods for evaluating crop irrigation demand. These methods normally involve estimation of the crop evapotranspiration for each crop on the farm, average rainfall for the area, crop coefficients, and soil data. The results from these methods can be used to determine an average schedule for when water needs to be applied to the field.

One of the first inputs needed in crop water use models is the estimation of the crop evapotranspiration for each crop on the farm. There are several methods for calculating evapotranspiration such as the radiation method, Blaney-Criddle method, the Hargreaves method, the Pan Evaporation method, and the FAO Penman-Monteith equation. Picking the right method depends on the availability of the needed input data and desired accuracy.

The FAO-modified Penman-Monteith equation was used because this method accounts for many climate variables. Using these variables yields more accurate results than the others. This method accounts for temperature, humidity, wind speed, and radiation. The FAO-modified Penman-Monteith equation differs from the classic Penman-Monteith because it implements equations for aerodynamic and surface resistance. The data required for this method is available through FAO's CLIMWAT software. This method also has been integrated into FAO's CropWat software, increasing the ability for iteration and calculations in mass.

This method provides only evapotranspiration based on a reference crop (normally grass) and evapotranspiration must be calculated in terms of each specific crop to determine the farm's water requirements. This comes in the form of tabulated dimensionless crop coefficients (K_c), which change throughout the growing season. Multiplying the crop coefficient and the reference evapotranspiration (ET_o) will yield crop evapotranspiration (ET_c).

The CLIMWAT database stores data from many weather stations around the United States. The closest of these stations is in Memphis, which is less than 60 miles from the farm. This should be close enough for this application. This database provides an average amount of rainfall per month for each month of the year. This is then used to calculate an effective rainfall which accounts for water that is lost due to factors like runoff. The method used here is the USDA SCS method where factors have been determined experimentally from soil moisture balances. These factors are multiplied by the actual rainfall to obtain effective rainfall (Dastane, 1978).

It is also important to specify the planting dates to understand which monthly climate data will be pertinent. Crop planting dates for soybeans and rice were sourced from Allen et al. (2000) and Hardke et al. (2019). The planting date each year can vary significantly based on weather conditions, so the median of a planting range should provide a reasonable design year for the water demand (Soybeans - May 28; Rice – April 10). Using crop evapotranspiration and precipitation, the net water requirement for the crop during a given period can be determined. The crop water requirement schedule does not necessarily dictate when the field should be irrigated because the soil can hold moisture which the crops can take up even if there has not been rainfall or irrigation on that day. Because of this, the model will need to account for soil parameters such as field capacity, wilting point, and infiltration rate. Once those are determined, a design timeline for crop water deficit will dictate a schedule when irrigation events should take place for the design year. A representation of this process is displayed in Figure 2.

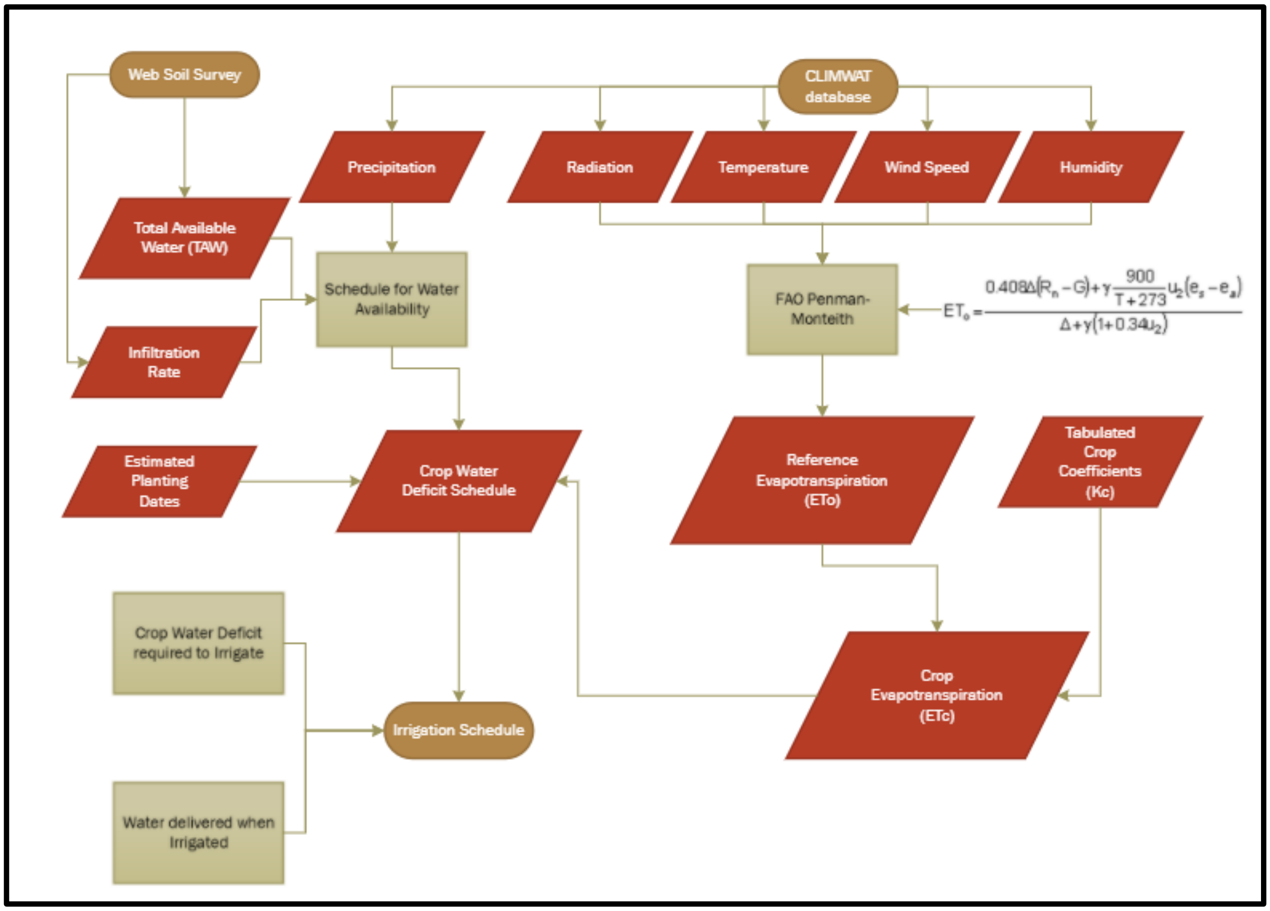

Figure 2: Flowchart depicting the process of irrigation scheduling development.

The climate data needed to run CropWat was sourced from the CLIMWAT database. The crop data was sourced from CropWat's database which has characteristic profiles for certain crops. The model option to adjust from transplanted to direct-seeded rice was utilized. The soil type at the farm was found to be a silt loam using the Web Soil Survey from (National Cooperative Soil Survey, 2021). Assumptions were made with regards to crop coefficients to match the predicted seasonal irrigation requirements to known historical irrigation requirements for each crop type (Henry, 2021).

After the data was inputted into the software, some settings were adjusted to make the irrigation schedule more accurate. Irrigation efficiency was estimated as: soybeans 70%, multiple inlet rice irrigation (MIRI) rice 85%, and zero-grade rice 98%. The irrigation timing and application were also adjusted. This is where iteration was performed to match a known average total seasonal irrigation amount for each crop (soybeans: 16 in, zero-grade rice: 19 in, MIRI rice: 24 in; Henry, 2021). Different reasonable settings were tested until total gross irrigation was approximately equal to these known amounts until the irrigation schedules in **Appendix B** were found. Most of the other settings remained default except for the percolation rate, which was adjusted from default to 1 mm/day. This was because the model was accounting for too much loss which was determined to be due to a higher percolation rate than would be expected on this farm. The efficiencies, expected total seasonal irrigation, and other settings were changed due to information from Henry (2021).

Using the irrigation schedule, the needed amount of irrigation water over different months of the season was approximated. The irrigation was modeled to determine the water needed to be pumped into the reservoir, on the monthly time frame, to meet the demand. The monthly time frame was used because it was important to decide for average conditions while still accounting for seasonal differences. The monthly time frame still accounts for the changing amount of water required throughout the growing season and for the seasonal change in solar radiation available. The irrigation events for each crop were grouped into the respective months and summed to get total irrigation per month, shown in Table 1. The sole exception to this was that rice flooding events in March were assumed to take place in May for this project (Henry, 2021). The given irrigation events were expressed as depths of water (mm) so unit conversion, as well as multiplication by crop acreage (soybeans: 225 acres, MIRI rice: 112.5 acres, and 0-grade rice: 112.5 acres), was needed to obtain total irrigation volumes. This process is detailed in spreadsheets in **Appendix B**.

Table 1: Monthly irrigation demand.

Month	Irrigation Volume (ac-ft)
April	131
May	40
June	120
July	294
August	125
Total	710

SOLAR ARRAY MODELING

To begin the analytic framework for solar pumping design, solar data was obtained from the solar design software HelioScope developed by Folsom Labs (2019). It is a web application that simplifies the design and sizing process for photovoltaic (PV) arrays. For this application, HelioScope was used to predict the energy produced by a proposed solar array configuration.

To start the modeling in HelioScope, the number of panels needed to fulfill the nominal pumping requirements of the system was determined. The first requirement was the type and number of panels needed for the system. Monocrystalline panels (320-watt, Heliene 60$^{\mathrm{MBLK}}$) were chosen based on their low cost, reliability and efficiency. The next step was calculating the number of panels required. The array was originally sized based on how much power it would take to fill the reservoir on the farm in two months. This is because the reservoir filling was the highest demand the pump would need to provide. The number of panels needed was found from the amount of power from the pump. After these calculations, a rough estimate of 72 panels was needed. Later it became apparent that some pumps could run on less solar power so the array was resized.

After inputting the panel type, the number of panels, amount of strings and modules, Helioscope showed the total nameplate power was 23 kW (DC). To meet the voltage inputs for the VFD, the panels were arranged in 3 strings with 24 modules each. However, it was later discovered that the number of panels could be reduced depending on which pump was used. Helioscope also computed diurnal solar energy data for each array size, on any given day. This diurnal solar data was organized to start the pump selection process.

Solar Tilt Angle Selection

To use the diurnal solar data from HelioScope, the tilt angle that delivered the greatest power output had to be found. HelioScope data was downloaded for nine different tilt angles ranging from 10 to 74 degrees and then compared. Since the pump is only running from January through July, the angle that produced the largest total energy output for those months was chosen. Figure 3 shows the energy output for nine possible tilt angles. The mounting angle which delivered the greatest overall output for January through July was 20 degrees.

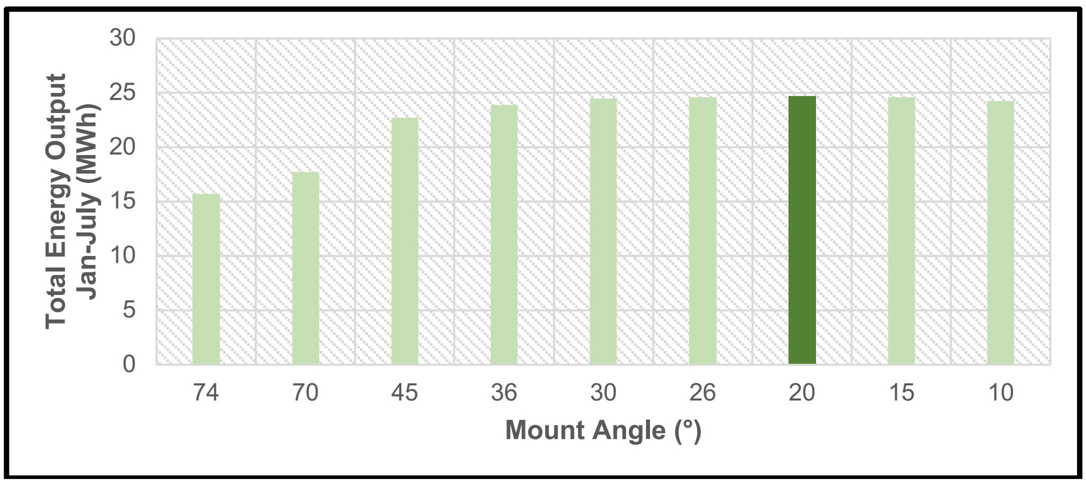

Figure 3: Total energy outputs for solar tilt angles ranging from 10 to 74 degrees.

After the optimum tilt angle was determined, diurnal HelioScope estimates were finalized. Subsequently, the average energy for each month was calculated. Since HelioScope calculated the nameplate panel power in watts, a simple conversion was used to convert to horsepower.

PUMP SELECTION

According to the previous modeling work for this farm, the pump needs to work against 20 feet total dynamic head (TDH) due to the elevation differences between the bayou and reservoir at the site. Since the solar power to the pump is changing throughout the day, a variable frequency drive (VFD) was needed to fluctuate the speed of the motor to increase efficiency. Maintaining a constant speed would cause the motor to overheat (and shorten its life) during the lower power availability in the morning and evening, or it would simply reduce the operating time each day and thereby fail to utilize the full solar potential.

Generating Alternatives

Based on the system's operating point range, three different mixed flow (MF) pumps were found that could potentially work for this system. This included the 8 MF, 10 MF, and 12 MFC pumps (Cascade Pump Company, 2018). Since the pumps will be operating at varying speeds with the VFD, variable-speed pump curves were evaluated to confirm whether or not crop water demand could be met.

Evaluating Alternatives

Using data collected from Helioscope at a solar panel angle of 20 degrees and the variable speed curves from Cascade, the flow rate for each hour of the average day in each month was predicted. To do this, lines had to be added to the pump curves provided by Cascade which can be seen in Figure 4 as green curves. The horsepower points were labeled at the intersection of the green curves and the highlighted 20 feet of total dynamic head. The curves had to be read backward to get a speed and flow rate for each power computed from the solar array by Helioscope. Figure 4 shows the hand-drawn iterations for the 8 MF curve. The 10 MF and 12 MFC curves can be seen in **Appendix C**. Since the variable speed curves are different for each pump, the following process was completed three times and the final outputs for each pump can be found in the second columns in tables 4, 5, and 6. This process is step 2 of the pump sizing for this project.

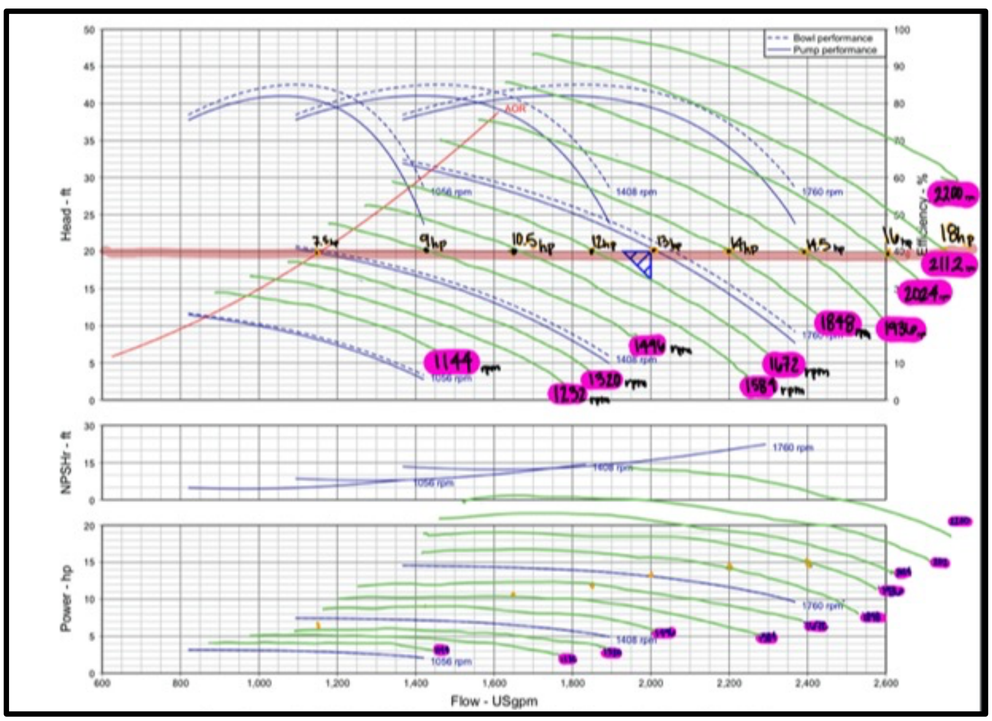

Figure 4: The process of computing daily power averages per month to calculate the average flow rates for each pump type. This specific pump curve is for the Cascade 8 MF pump. The variable speed pump curves were created by Thornton (2021).

When evaluating these pumps, power must be derated before looking at variable speed curves. All pumps had the same amount of power delivered from the panels. The power from the panels travels through a VFD to the motor before being delivered to the pump. There will be some energy loss from the VFD (about 2%), but it was neglected in these calculations. The losses from the motor will not be negligible. Motor efficiency changes based on the load. Solar radiation changes throughout the day, so load changes had to be accounted for. Efficiency was adjusted based on the load the motor experienced this was found in a Nidec motor curve.

Each alternative operates at different speeds and flow rates for each corresponding power supply value, which can be found in

Table 2. For the 10 MF pump, available power less than 7 hp will not be operational, therefore there is zero flow and no speed. For the 12 MFC pump, power below 5 hp was non-operational with no flow or speed. Because each pump has different power requirements for the same flow rates the number of panels required to run each pump will be different. For the 12 MFC pump, 72 panels were required. While only 60 and 54 panels were required for the 10 MF and 8 MF pumps respectively.

Table 2: Flow rates for the 8 MF, 10 MF, and 12 MFC pumps, based on supplied power.

Power supplied (hp)	Flow rates from 8 MF Pump (GPM)	Flow rates from 10 MF Pump (GPM)	Flow rates from 12 MFC Pump (GPM)
>5	0	0	0
>7	0	0	750
8	1250	1300	500
10	1575	1650	1000
12	1850	1875	2000
14	2200	2050	2200
16	2600	2200	2300
18	2700	2350	2600
20	2800	2475	3000
22	2900	2570	3100
24	3000	2600	3200
26	3150	2650	3400
28	3200	2750	3700

After the diurnal pattern of speed and flow rates for each month were calculated, the final step was comparing the pump alternatives. Figure 5 illustrates a description of this process.

To begin this process, the amount of water that can be added to the reservoir for each timestep was determined, see Equation 1.

$$W_a = Q * 60\frac{min}{hour} * D * 3.069 \times 10^{-6}\frac{ac-ft}{gal} \qquad (1)$$

where

W_a = Average amount of water added to the reservoir for a certain timestamp (ac-ft/hr)

Q = Flowrate (GPM)

D = Days in the month.

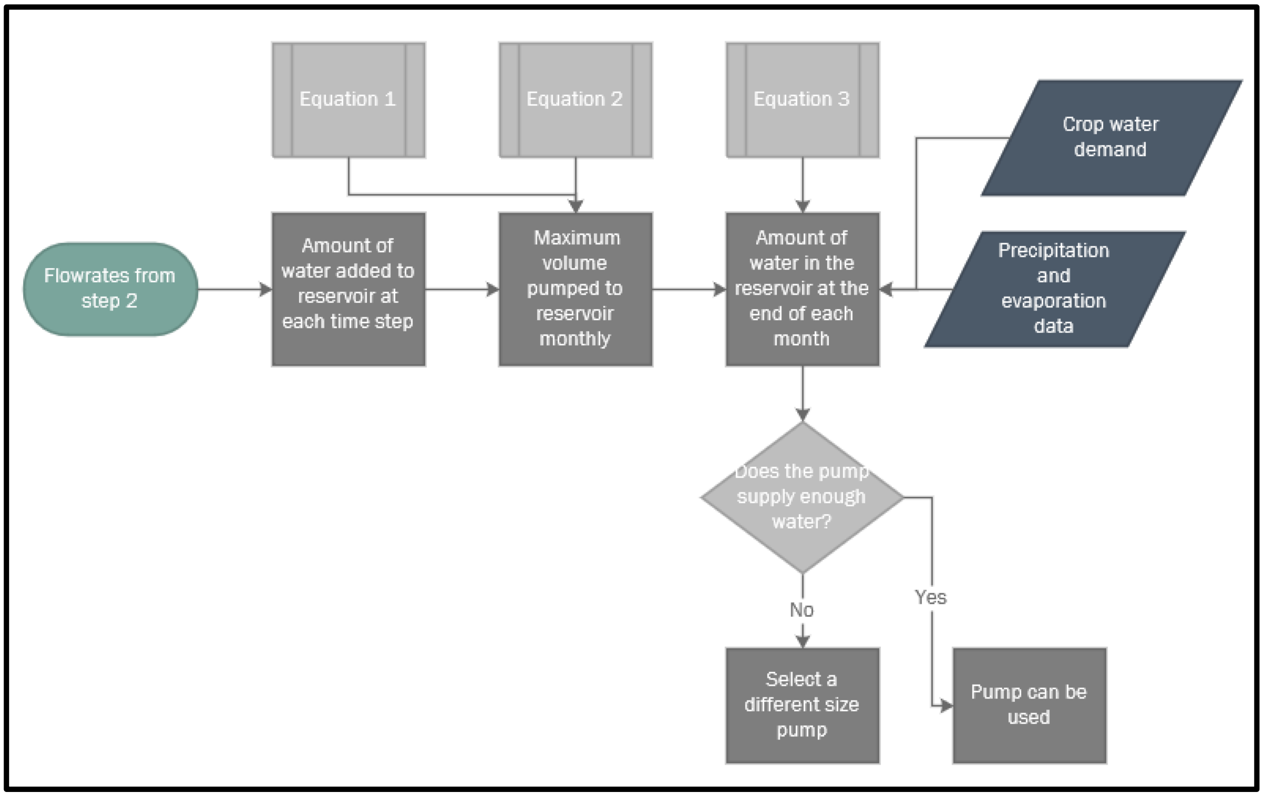

Figure 5: Process of sizing a pump at variable speeds to meet crop water demand.

After the pump flow rates were calculated, the total amount of water that is added to the reservoir at the end of each month was determined. This was calculated with the following equation:

$$Total_W = \sum W_a \qquad (2)$$

where

$Total_w$ = Total water added to the reservoir at the end of the month

W_a = Average amount of water added at each timestamp.

These values are maximums and can be altered by designing a pumping schedule to produce less water waste. Equations 1 and 2, were used to calculate the number of panels needed and the water balance for each pump. After the amount of water the pumps can provide was calculated, a water balance was used to check that enough surface water is added to the reservoir to meet the demands of the irrigation schedule. This balance accounts for the amount of water pumped out each month for irrigation, evaporation, precipitation, and the water pumped in from the bayou. For each pump, the full waster balance is shown in Table 4. Note that the total amount of water leftover in the reservoir at the end of August was about 47, 44 and 45 ac-ft for the 12 MFC, 10 MF and 8 MF pumps, respectively.

Table 3: Water balance for the 12 MFC pump using 72 solar panels.

Month	Water Pumped In (ac-ft) For the Pump Alternative			Water Pumped Out (ac-ft)	Evaporation (ac-ft)	Precipitation (ac-ft)	Volume of Water in Reservoir (ac-ft) For the Pump Alternative[a]		
	12 MFC	10 MF	8 MF				12 MFC	10 MF	8 MF
January	95	89	96	0	1	10	104	98	105
February	104	92	96	0	1	11	218	200	211
March	117	115	114	0	2	12	345	325	335
April	131	122	115	131	5	14	349	325	328
May	126	57	54	40	7	14	349	349	349
June	125	117	111	120	9	9	349	346	341
July	116	116	123	294	9	10	172	169	170
August	0	0	0	125	8	8	47	44	45

[a]For pump alternatives, 12 MFC, 10 MF and 8 MF, the required number of solar panels was 72, 60 and 54, respectively.

Average evaporation in millimeters was found on the National Oceanic and Atmosphere Administration (NOAA) website. NOAA uses relative humidity and dry bulb temperature to calculate the evaporation for each area in the US (National Oceanic and Atmosphere Administration, 2021). This value in mm/month was multiplied by the surface area of the reservoir and converted to ac-ft. Average monthly precipitation information was also found from NOAA. Precipitation in inches per month was multiplied by the surface area of the reservoir and then converted to ac-ft. The following equation was used to calculate the amount of water in the reservoir for each month:

$$W_n = W_{n-1} + W_{pump-in} + W_{precip} - W_{evap} - W_{pump-out} \tag{3}$$

where

W_n = Amount of water in the reservoir per month (ac-ft)

W_{n-1} = Amount of water in the reservoir from the previous month (ac-ft)

$W_{pump\text{-}in}$ = Amount of surface water pumped into the reservoir (ac-ft)

W_{precip} = Amount of water from precipitation into the reservoir (ac-ft)

W_{evap} = Amount of water leaving the reservoir due to evaporation (ac-ft)

$W_{pump\text{-}out}$ = Amount of water pumped out of the reservoir to irrigate crops (ac-ft).

Pump Evaluation Results

In any given month, the pump could deliver the estimated maximum volume of water to the reservoir. In March, April, and May, the potential flow would cause the reservoir to overflow, leading to water waste and erosion. (If the farm ever gets grid power to the site, the extra capacity could be utilized to offset other electrical needs of the total farm research operations). Since less water is used than what can be provided, this indicates an excess capacity will exist, acting as insurance for unusual patterns of overcast days. Manual or automatic controls would be needed turn off the pump when the reservoir is full. All three pumps considered were capable of meeting the needs of the system. Smaller pumps were considered (not shown) that were not adequate. The deciding factor for selecting a pump will come down to cost. The cost for each is as follows:

- $31,000 for the 12 MFC;
- $23,000 for 10 MF; and
- $15,000 for 8 MF.

The number of panels needed to run the 12 MFC, 10 MF, and 8MF is 72, 60, and 54 respectfully. Since the 12MFC pump is already on-site it would be the top choice. However, if there was no pump on-site the 8 MF pump would be the best option. This is because has a lower initial cost and requires the lowest amount of solar panels to operate.

Economic Impacts

According to McDougall (2015), an estimate for the amount of fuel saved from omitting the use of a diesel surface water relift is $0.50 per acre-in per 10 feet of TDH. Based on this information, the design with 20 feet of TDH and approximately 814 acre-ft of water pumped throughout the year, would have a diesel fuel cost of $9,768 ($0.50 /ac-in/10 ft *20 ft *814 ac-ft *12 in/ft = $9,768) The cost of each panel is $256, which can be used along with an estimated mount cost to provide a total capital cost for each system. Given these costs and benefits, both the rate of return and simple payback period were calculated and can be seen in Table 4.

Table 4: Economic summary for each pump alternative.

	Cascade 8 MF Pump	Cascade 10 MF Pump	Cascade 12 MFC Pump
Cost of Panels	$13,824	$15,360	$18,432
Cost of Mount	$2,915	$3,027	$3,252
Cost of Pump System	$15,000	$23,000	$31,000*
Savings from Diesel	$9,768	$9,768	$9,768
Rate of Return (n=25)	31%	23%	45%
Simple Payback Period	3.2 years	4.2 years	2.2 years

*Will be 0 in our case since the farm already owns this pump

Through this analysis, the 12 MFC pump is chosen for this specific system. If a new pump had to be purchased, the 8 MF pump system would be more economical.

Environmental Impacts

In terms of the environmental impact, it is important to reiterate the problem with the over-withdrawal of the

MRVAA aquifer. The sustainable withdrawal rate in 2012 was estimated as 3,374 MGPD, while the actual withdrawal rate in that year was measured as 8036 MGPD (Swaim et al., 2016). This is likely to lead to water level decline which can make it more difficult and require more energy to pump water from this aquifer for those who need it. Groundwater is also important to the water cycle and feeds into some surface water sources. Sources such as streams could see a reduction in water level due to this. It is also possible for the removal of water from underneath soil could compromise its structural integrity (Konikow and Kendy, 2005). In the eastern Arkansas area, a confined aquifer below the MRVAA, Sparta, has seen increased use when withdrawals from the MRVAA are high. Sparta is a drinking water source for the area so using this aquifer could impact the local drinking water supply (Reba et al., 2017). The proposed system would pump 814 ac-ft (265 MG) in a year or 0.727 MGPD, which would account for around a hundredth of a percent of the deficit. This deficit estimate is also nearly a decade old and could have changed. This would require many farmers (over 6000 similarly sized farms, a reasonable number) to make up this deficit. So, the widespread use of surface water irrigation can significantly lower the deficit given enough adoption occurs. Demonstration of this method at the research farm could help to encourage adoption.

The other significant environmental impact to discuss with this project is the mitigation of climate-change-inducing emissions through the use of the solar array. Irrigation pumping on an off-grid system is typically powered using a diesel pump. Not only are diesel pumps less efficient than most electric pumps, but burning diesel also produces emissions that are known to contribute to climate change. Assuming a diesel-powered pump, it was computed that a similar surface water irrigation system powered by diesel would consume 4,600 gallons of diesel per year. Using the Comet Farm Emissions Tool (USDA, 2020) we were able to estimate the emissions produced when this amount of diesel is combusted. Approximately 103,000 pounds of CO_2 equivalent would be produced each year, with 2.22 lb of these emissions being nitrous oxide and 13 lb being methane.

Social Impacts

One impact to discuss with this system is that it will likely be easier to manage for the farmer with regards to fueling. The diesel engine would need to be refilled often inconveniencing the farmer, whereas this is not the case for solar power. The system can pump when solar energy and water are available and be automatically shut off with a float switch to prevent overflow. Having solar panels on the farm is also positive for the public image of the farm. The smell and noise from a diesel engine would also likely be more of a nuisance to the farmer and possible neighbors than the solar panels and electric pump.

Conclusion

NERREC needs a system that pumps enough water to its reservoir for irrigation during the growing season. After evaluating different design alternatives, a solar pumping system was developed to solve the problem. Crop water demand, solar radiation data, and pump sizing were the main components of the engineering design process. Pumps were sized to meet crop water demand using a variable frequency drive. A variable frequency drive was selected to allow the motor/pump to continue to operate (and utilize available energy) even during reduced solar output that is characteristic in the morning and evening. Through the engineering design process, the team was able to make several recommendations to the client.

RECOMMENDATIONS

This team recommends the client use the Cascade 12 MFC pump, with 72 solar panels, to supply surface water to the irrigation reservoir. This reflects the cost savings when using the pump already available on site. The 12 MFC pump delivers enough water to meet the crop irrigation demands while still having the excess capacity (approximately 7%) to account for cloudy weather and uncertainty in rainfall. However, if the client did not have any pumps on-site, the 8 MF pump would be the recommendation. The Cascade 8 MF pump only requires 54 solar panels to meet the estimated water demand. This pump has a lower initial cost than the other two pumps compared in this design process.

The Heliene solar panels, quantity 72, are recommended to be arranged in 3 strings of 24 modules. This setup is shown in Figure 6. The panels would be mounted on a fixed array that's held at 20 degrees year-round. A mounting rack was designed using 2 x 2 x 0.25-inch square steel tubing. The location of these panels will be on the downslope of the reservoir.

Through these recommendations, the hope is that the client can implement large-scale solar pumping and inspire others to do the same.

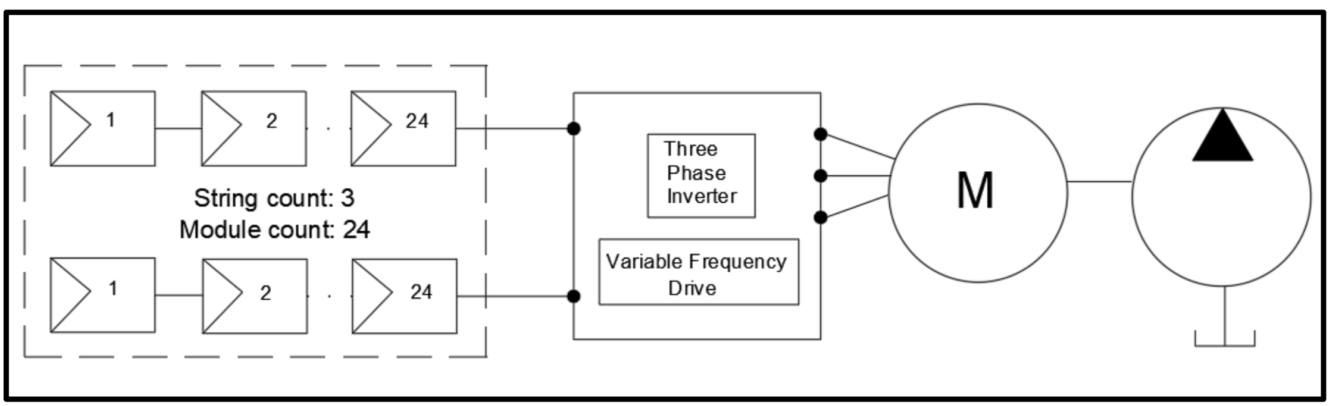

Figure 6: Basic wiring diagram for Heliene panels, quantity 72, connected to a VFD, motor, then pump.

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RESEARCH & EXTENSION
University of Arkansas System

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UNIVERSITY OF ARKANSAS

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May 15, 2021

To: ASABE Student Design Competition Judging Committee

RE: Certification of Project

As per the rules of the Gunlogson (Open) National Student Design Competition. I hereby certify that this submission is not part of any other ASABE student design competition.

Sincerely,

Thomas A. Costello, P.E., Ph.D.
Associate Professor of Biological Engineering
Undergraduate Program Coordinator
Senior Design Coordinator

The University of Arkansas is an equal opportunity/affirmative action institution.

APPENDICES

APPENDIX A

This appendix shows the stage storage table that was computed to find the volume of the trapezoidal reservoir. The total volume is 349 ac-ft with 1.5 feet of freeboard.

Stage (ft)	Bottom Width	Volume (ft^3)	Volume (ac-ft)
0	1000	0	0
0.5	998	899600	21
1	996	1798397	41
1.5	994	2696391	62
2	992	3593579	82
2.5	990	4489958	103
3	988	5385528	124
3.5	986	6280286	144
4	984	7174229	165
4.5	982	8067357	185
5	980	8959667	206
5.5	978	9851156	226
6	976	10741824	247
6.5	974	11631668	267
7	972	12520685	287
7.5	970	13408875	308
8	968	14296235	328
8.5	966	15182762	349
9	964	16068456	369
9.5	962	16953314	389
10	960	17837333	409

Appendix B

This appendix shows the irrigation schedules for soybeans, MIRI rice, and zero-grade rice.

Soybeans

date	net irr (mm)	net irr (in)	gross irr (in)	gross irr (ac-in)	gross irr (ac-ft)
5-Jul	43.2	1.70	2.27	510	42.5
12-Jul	41.5	1.63	2.18	490	40.8
20-Jul	45.8	1.80	2.40	541	45.1
30-Jul	44.8	1.76	2.35	529	44.1
9-Aug	43.9	1.73	2.30	519	43.2
19-Aug	42.8	1.69	2.25	506	42.1
30-Aug	40.7	1.60	2.14	481	40.1

MIRI Rice

date	net irr (mm)	net irr (in)	gross irr (in)	gross irr (ac-in)	gross irr (ac-ft)	
21-Mar	49.2	1.94	2.28	256	21.4	push to May
5-Apr	98	3.86	4.54	511	42.6	
10-Apr	60.4	2.38	2.80	315	26.2	
1-Jun	54.3	2.14	2.52	283	23.6	
12-Jun	50.4	1.98	2.33	263	21.9	
22-Jun	55.3	2.18	2.56	288	24.0	
2-Jul	54.9	2.16	2.54	286	23.8	
12-Jul	53.3	2.10	2.47	278	23.1	
25-Jul	52	2.05	2.41	271	22.6	

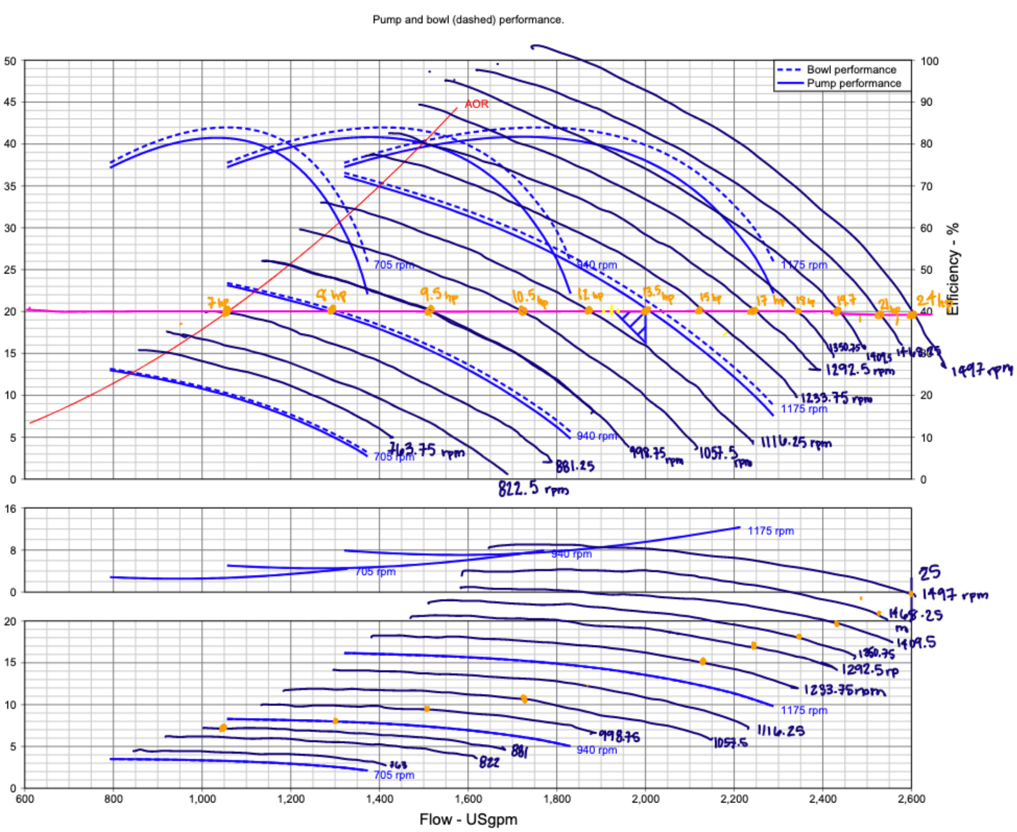
Zero-grade Rice

date	net irr (mm)	net irr (in)	gross irr (in)	gross irr (ac-in)	gross irr (ac-ft)	
21-Mar	49.2	1.94	1.98	222	18.5	push to May
5-Apr	98	3.86	3.94	443	36.9	
12-Apr	66.3	2.61	2.66	300	25.0	
5-Jun	65.2	2.57	2.62	295	24.6	
20-Jun	68.4	2.69	2.75	309	25.8	
6-Jul	69.3	2.73	2.78	313	26.1	
21-Jul	69	2.72	2.77	312	26.0	

APPENDIX C

This appendix includes variable speed curves used to size a pump system. Extra speed curves were drawn in (dark blue for 10MF and yellow for 12 MFC) for better accuracy.

10 MF



CASCADE PUMP COMPANY

Multi-Speed Performance Curve
Page 1 of 1

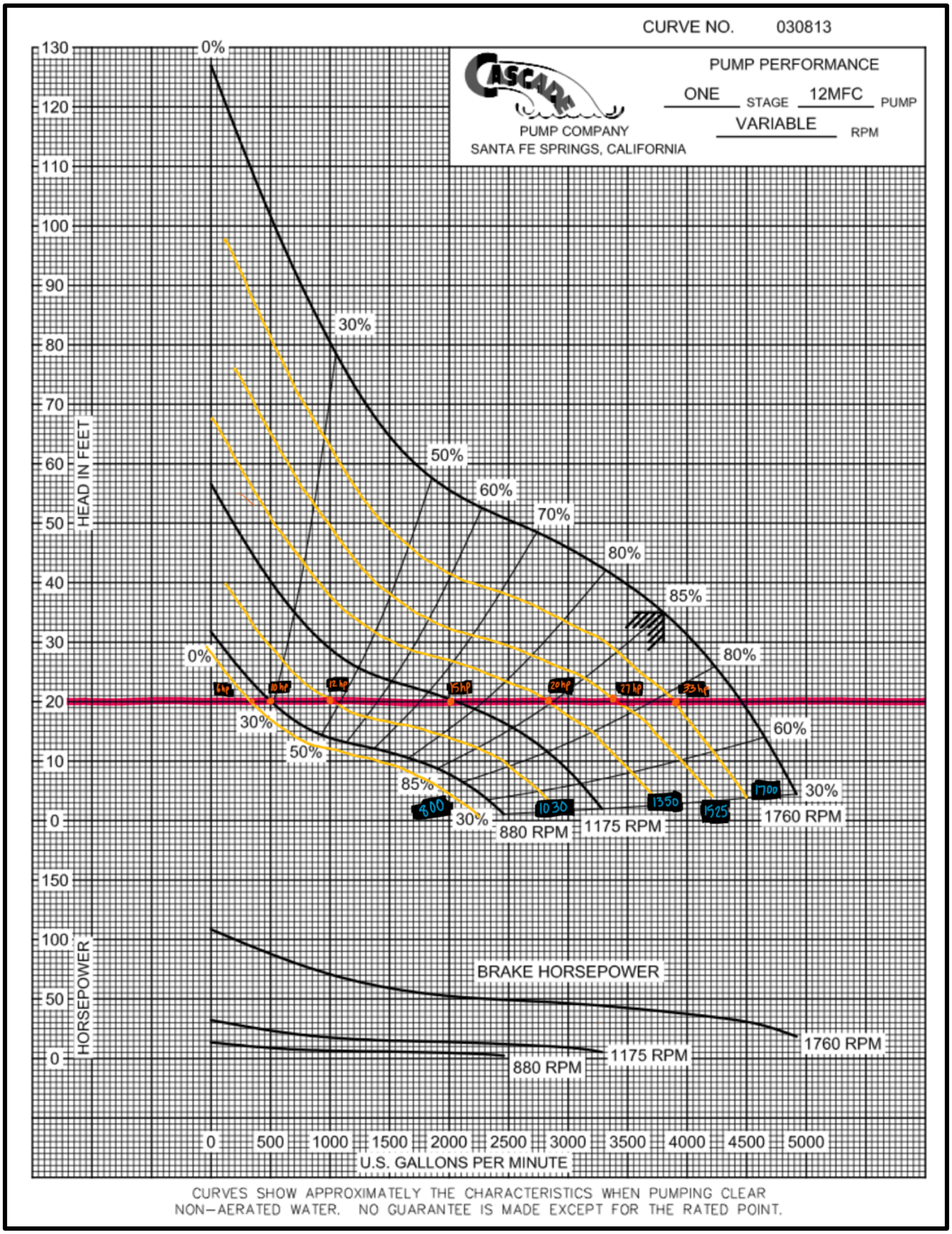
Customer	: UNIVERSITY OF ARKANSAS
Customer Reference	:
Job Name	: Solar Irrigation Pumping Project
Pump Model	: 10MF_CD4_A_RPM1175
Quote/Serial No.	: 21-105

Curves show approximately the characteristics when pumping clear non-aerated water. No guarantee is made except for the rated point.

Quantity	: 1	Nominal speed	: 1170 rpm
Flow, rated	: 2,000.0 USgpm	Stages	: 2
Differential head / pressure, rated / TDH	: 20.00 ft	Efficiency (bowl / pump)	: 79.77 / 76.05 %
Speed, rated	: 1175 rpm	Power, rated	: 13.53 hp
Impeller trim, rated	: 39	NPSH required	: 9.54 ft
Site Supply Frequency	: 60 Hz	Fluid density, rated / max	: 1.000 / 1.000 SG
Date	: 03/31/2021	Item Number	: B
		Application	:

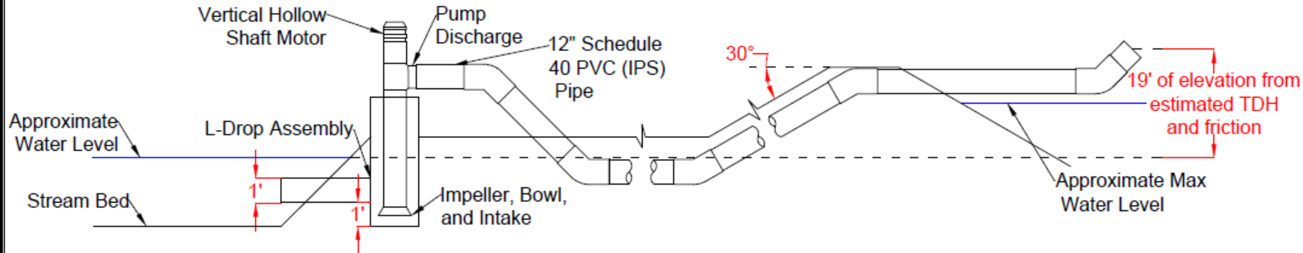
ISO 9001:2015 CERTIFIED
WWW.CASCADEPUMP.COM
MADE IN USA SINCE 1948
HYDRAULIC INSTITUTE PROUD MEMBER

12 MFC


CURVE NO. 030813
PUMP PERFORMANCE
ONE STAGE 12MFC PUMP
VARIABLE RPM
CASCADE
PUMP COMPANY
SANTA FE SPRINGS, CALIFORNIA
HEAD IN FEET
HORSEPOWER
BRAKE HORSEPOWER
0% 30% 50% 60% 70% 80% 85% 80% 60% 30%
880 RPM
1175 RPM
1760 RPM
6hp 10hp 12hp 15hp 20hp 27hp 33hp
800 1030 1350 1525 1700
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
U.S. GALLONS PER MINUTE
CURVES SHOW APPROXIMATELY THE CHARACTERISTICS WHEN PUMPING CLEAR
NON-AERATED WATER. NO GUARANTEE IS MADE EXCEPT FOR THE RATED POINT.

APPENDIX D

This drawing is not drawn vertically to scale to provide greater detail in the pump and piping system. The pipe chosen was a 12” Schedule 40 PVC pipe. A pipe length of around 80’ was assumed to travel from the pump to the reservoir. Using a maximum flow rate of 3000 GPM, approximately 1 ft of friction head loss was calculated. From the assumed 20 ft of TDH, this resulted in an elevation change of 19’. It is important to bury the pipe to prevent UV damage over time. The exposed sections should be painted to provide more protection.



BENG 4823	Solar Irrigation Pumping	Spring 2021
Team 9	Pump Installation Cross-Section	Christian Hitt