Village Supply: PV/Pump Subteam, Fall 2014

Qingjing Gong, Anqi Wang, Erika Axe

December 12, 2014

Abstract

The PV/Pump Subteam section has worked on how to modify and improve upon the ideas and models already in place for design of pumps in villages for the Fall 2014 Semester; this group is a subset of the entire Village Supply Team in the AguaClara Student Project Team at Cornell University. In general, this subset has worked toward having single electric pumps that send water to the town and lifts water from the well at ground level to an AguaClara facility/distribution system, deliberating types of pumps and pressure requirements for equal distribution, balancing cost and efficiency of pumps, and evaluating the different options for the design of the photovoltaic and pump system. Among the different designs for the photovoltaic and pump system, this section will be looking at two main options. The first option will be to divide the power between the two pumps, create a simple control system for easily maintenance, and to design the photovoltaic system to be able to handle cloudy, winter days. The second option to be looked into will be to divert all the power to the first pump on cloudy days and to allow the control system to automatically divert all of the power to the well pump when the chlorine contact tank isn't full—thereby allowing the second option to be more easily implemented.

Table of Contents

Introduction

The designed system was based on Gufu Village in India, shown in Figure 1 below. The elevated storage tank supplies over 50% water for daily usage. To fill the elevated storage tank, the water is pumped from a well, which is half a kilometer outside the village, by using diesel, electric or solar pumping. A three-tiered pipe system is used to pipe the water to each house. Before sending the water to each household, the water will be treated through a pressurized LFSRSF(Low Flow Stacked Rapid Sand Filter). Based on the design ideas for 2013, the assumptions are: per capita demand is 100 liters per day; village population of 500 people; and 5 people per household.

Figure 1 Map of Gufu Village and Well

Literature Review

The design for this project is primarily based on AguaClara Project in Spring 2014. Several valuable ideas, from who focused on the village supply system, can be used in the current new design.

Use a dimensionless parameter, Π_Q, to represents equity in flow between houses in the village. Assume each house would have the same flow rate, this means that Π_Q should be 0. As this aim may not be assessed because of head loss difference or leakage problems, the team can set the boundary of Π_Q to be 0 to 10%. The equation in terms of head:

$$\Pi_Q = \frac{\sqrt{(h_{Equity} - h_{LEMinimum})} - \sqrt{(h_{Equity} - h_{LEMaximum})}]}{\sqrt{(h_{Equity} - h_{LEAverage})}} \qquad \text{Equation (1)}$$

Since the system relies on solar pumps to deliver water to each house, use following equation to calculate the amount of solar power generated at a given location each year to help with selecting pumps. First, gather data to calculate the monthly average daily solar insolation values (H) and the monthly average clearness index values (K_T) in Gufu village.

The declination angle is the angle at which sunlight hits the surface of earth. This is used to figure out how much sunlight a given location can receive.

$$D = 23.45\, sin[360 \frac{(284+N_{JD})}{365} \frac{\pi}{180}] \qquad \text{Equation (2)}$$

The daily solar insolation is the amount of solar power that hits the earth each day.

$$H_d = \overline{[H(1.39 - 4.03K_T + 5.53K_T^2 - 3.11K_T^3)]} \qquad \text{Equation(3)}$$

The solar insolation ratio relates the amount of sun power that hits a horizontal surface to the amount that hits a tilted surface.

$$R_r = [(1 - H_d/H)R_{Bbeta}] + H_d/H * (1 + cos(S_M) + [\rho_{Ref}(1 - cos(S_M)]/2 \qquad \text{Equation (4)}$$

$$H_t = H \times R_r \qquad \text{Equation (5)}$$

Then, calculate the actual output of the solar panel

$$\eta = \eta_r [(1 - (T_C - T_A) - \beta (T_A - T_M) - \beta (T_M - T_F)] \qquad \text{Equation (6)}$$

$$ActualOutput = H_t \cdot \eta \cdot der\vec{a}tingfactor \qquad \text{Equation (7)}$$

Last, in the village, calculate the total volume of water pumped each day to meet the actual water demand

$Q = \frac{P\epsilon}{h\rho g}$ Equation (8)

In this case, the pump models can be determined according to pump power, pump head and cost.Table 1 explains the definition of variables in equations above.

Table 1 Definition of Variables

Variable	Definition
$\Pi_{SunHours}$	Percentage of each day for which there is sufficient sunlight to operate the PV pump. For the Gufu Village, this is assumed to be 25% (6 hours/24 hours)
N_{JD}	Number of Julian day, ranging from 1 to 365. One day was chosen for the 15th of each month (i.e. January 15 is the 15th Julian day)
D	Declination angle relative to the equator
H_d	Diffuse component of daily insolation sum, thermal energy per square meter
$\vec{H}$	Global daily insolation sum, thermal energy per square meter
K_T	Monthly average clearness index
R_r	Ratio of total insolation on a tilted surface to that on an equivalent horizontal surface
R_{Bbeta}	Ratio of beam insolation on a tilted surface to that on an equivalent horizontal surface
S_M	Optimum PV tilt angle for a month, measured from the horizontal
ρ_{Ref}	Reflection coefficient, with 1 being the least reflective
H_t	Monthly average total daily insolation on a tilted surface, thermal energy per square meter
β	Solar cell temperature coefficient of PV efficiency, 1/degree C
η_r	Solar cell efficiency at rating conditions
η	Overall panel efficiency
T_M	Mean monthly ambient air temperature
T_A	Monthly average air temperature
T_C	Monthly average cell temperature
ϵ	Pump Efficiency

Methods

In order to acquire all the data for all of the additional data and insights, this group has looked into the past research of AguaClara Village Supply Team and extrapolated and continued in the direction of the research being done. The team has also looked into the company data of the different materials and pumps being used in India as well as contacting the AguaClara representative in India, Maysoon, in order to collect the most recent information and data from India itself. Additionally, research has been done using outside sources dealing with water supply and pump systems. In order to determine the conclusion of which pump system to implement, the group also used a decision matrix in order most fairly make a decision of which pump system is best; this was done by looking at several different qualifications of all the main factors that make up a good pump system and quantitatively comparing the designs on a one to ten scale (and then weighting the results together) to create a fair grading system of the two.

Results and Discussion

Pump Availability in India:

There are different kinds of commercial pumps based on Pumpkart website, which is the largest online pump store in India. The power rating is in the range of 0.33 HP to 10 HP (or 0.25 KW to 4 KW); the pressure capacity is 0.65 bar to 160 bar; and the flow rate capacity is 120 L/min to 350 L/min. To determine which pump is needed, the team should calculate the required pressure and flow rate. The team communicated this information with Maysoon, who has been working at Gufu Village in India.

Solar Panel

According to Maysoon, the solar pump is paired with HBL solar panels in Gufu village. HBL has a wide range of panels, which can compliant to design qualification and type approval IEC61215. IEC 61215, IEC 61730 Part 1&2, IEC 61701, and UL 1703. Figure 2 shows a typical solar panel sold by HBL.

Figure 2 Solar panel in HBL

HBL provides a charge controller that can maximize energy harvest from the Photovoltaic cell array, which incorporates dynamic MPPT (Maximum Power Point Tracking) algorithm. Figure 3 shows a typical charge controller sold by HBL. The MPPT constantly adjusts the operating points of the array that ensures the delivery of maximum available power from PV array to battery bank. While charging, it regulates battery voltage and output current based on the amount of energy available from the PV array and state-of-charge of the battery. Off-grid solar power conditioning unit integrates the advantages of solar charge controller, inverter and charger into a single module to smartly manage the power utilization between battery, PV array and grid. It provides uninterrupted AC power using a battery bank. The power conditioning unit converts DC power by SPV modules and stores it in the battery bank providing a good quality AC power. What is more, the charge controller is low maintenance.

Figure 3 Example battery

http://www.hbl.in/home

As for the efficiency of the solar panels, the Grundfos company has solar panels with known efficiency graphs as can be seen by the SQFlex solar performance curve in Figure 4 (Q represents flow while H represents the head). One possible concern for the solar arrays is that its efficiency degrades as time goes on. However, for an average company's solar panel, the efficiency decreases by about 0.5% per year. A loss of efficiency would probably not be noticed until at least 10% is lost, which would take about 20 year. In a twenty year period, most of the system components would also need to be replaced before the solar panel and the solar panel itself would also be checked on, therefore the loss of efficiency is negligible.

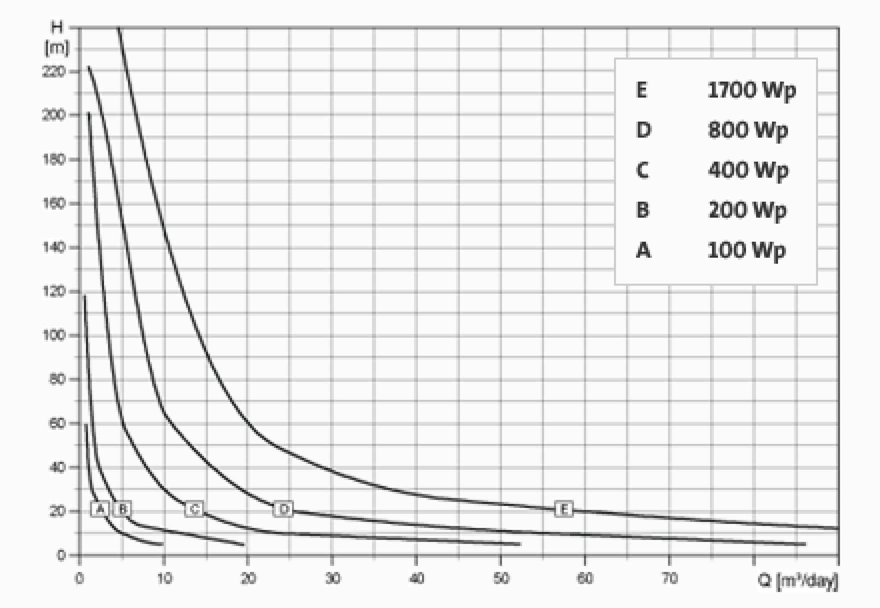


Figure 4: Grundfos Solar Efficiency Graph

Another one of the things considered for the solar array is the possibility of making the solar panel angles manually adjustable. Having major changes in weather between each season of the year in India, as well as changes in the sun's angle in itself, the solar panels will have a greater efficiency at different angles throughout the course of a single year. In order to get the most yield out of the solar panels, it was questioned whether or not the panels could be manually adjusted with the panels that are already being used. There are many companies that offer solar panels with automatic angle adjustments; these adjustments can increase the efficiency of the system by 40%. Because automatically adjusting solar panels are much more expensive, having manually adjustable panels would allow a similar increase in efficiency at a much lower cost. Few sources have used manually adjustable solar panels in the field, further research into journals and databases as to any information on this process would be needed to find exact calculations on which angle is best at what time. Generally speaking, solar panels should have an angle equal to whatever degree of latitude the panel is located at. In the summer, panels can be adjusted to a lower angle. In the winter, panels can be adjusted to a higher angle in order to catch more of the sun's rays since the sun is lower in the sky. There are widely available solar panel adjustable mounting racks that could be used to change the angle of the panel. Most cost between $80 and $400 depending on company, quality and size.

It would be possible but to create new panel mounts that can be adjusted. With an adjusting panel mount, it would also be necessary to make permanent instructions and markers on the mount itself that instruct the proper angle for whatever time of the year it is. This would also require research in order to figure out with angle is the most efficient at any given time of the year (this goes for both Gufu Village and any other village that this idea would be applied to). An example of how these mounts could look and operate can be seen in Figure 5 below. The benefit to using a mount like this would be that it is extremely easy to adjust and would be user-friendly for the people in the village to adjust and work with throughout the year.

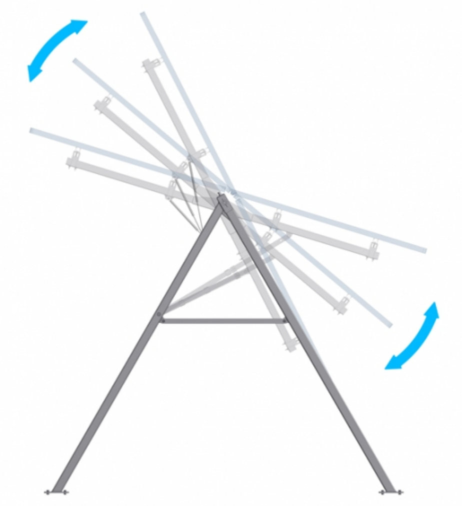


Figure 5 Example of a manually adjustable solar array

In a case study in Malaysia, tests were done trying to make solar panels more efficient by trying to make sure the solar panels were most efficiently taking up energy (Malaysia usually does not go a full day with a completely clear sky and would need solar panels to make the most of what light there is, something that might be comparable to India's different seasons)(Lim et al., 2014) . Instead of using monofacial solar panels, this group chose to use bifacial solar panels (all of these studies only considered mono-crystalline solar cells). Bifacial solar panels would have the ability to change light into electricity using both its front and rear sides. This works by allowing the panels to make use of both reflective and direct sunlight and has been claimed to even boost energy yield by as much as 50 percent when installed on vertical panels. Both the front and rear surfaces would collect direct sunlight as well as diffused sunlight with the use of an appropriate concentrator or reflector. The group in Malaysia took advantage of the use of bifacial solar arrays and spent most of their research looking at the difference in methods of reflectors and mirrors to maximize the amount of diffused sunlight. An example of what a vertical bifacial solar array might look like can be seen in Figure 6 below.

Figure 6 Example bifacial solar panels

A bifacial solar panel comprises 6 bifacial solar cells which are soldered in series on a transparent acrylic plate with a distance of 13.5 cm between solar cells, then covered by a thin plastic film to fix their positions, and finally covered by another transparent acrylic plate. By using this method they were able to produce 38.1% ± 2.83% more energy from their solar panels in comparison to the monofacial solar panels just by having their solar panels horizontally oriented as seen in Figure 7. It is speculated that were these panels tested vertically, the amount of energy created would have been even higher. This method might also be worth looking into as another way to utilize sunlight in India most effectively as well as manually adjustable solar panels in order to prevent the need to have the residents of the village adjust the angles of the solar panels so often.

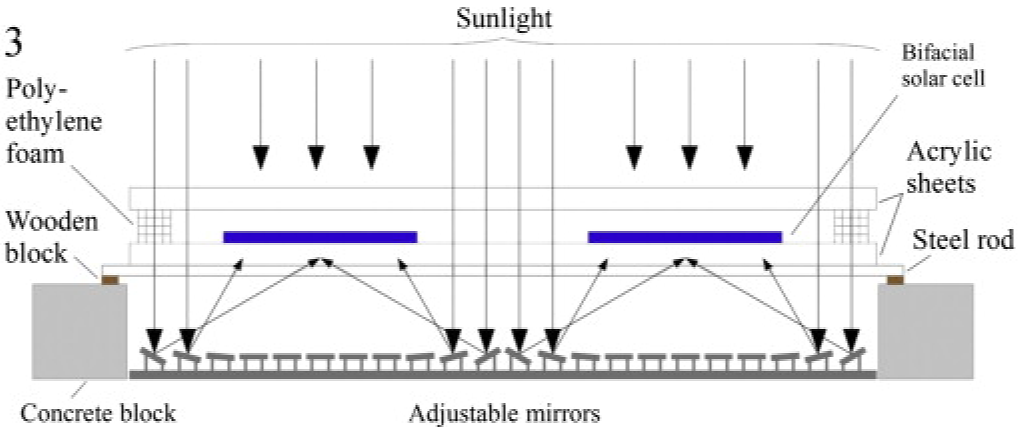


Figure 7 Experiment Setup with small adjustable mirrors

Decision Matrix

The decision matrix was made based on two alternatives and six criteria. A score from 1 to 10 will be given to each alternative based on the criteria. A score of 10 means the alternative is more likely to meet the criteria, and the score of 0 means the alternative could not meet the criteria at all. Table 2 shows the decision matrix, and corresponding scores. As can seen Table 2, one pump system got a total score of 7.25, and two pump system got a total score of 8.35. According to Figure 8, two pump system has a higher MCDA(Multi Criteria Decision Analysis) score and a lower cost. (The cost value is from Distribution Subteam) In this case, the team would like to choose a two pump system. The rest of report would based on a two-pump system.

Table 2 Decision Matrix

CRITERIA	Weight(1-100)%	Alternatives	
		One Pump	Two Pump
Meets regulatory requirements	20	9	9
Lifespan	5	8	8
Dependability	15	7	9
Safety	15	6	9
Ease of operation	5	7	7
Location/footprint	5	6	9
Risk of technology	10	2	9
Energy efficiency	25	9	7
Final Score:		7.25	8.35
Captical Cost Estimate:		$ 15,630	$ 10,370

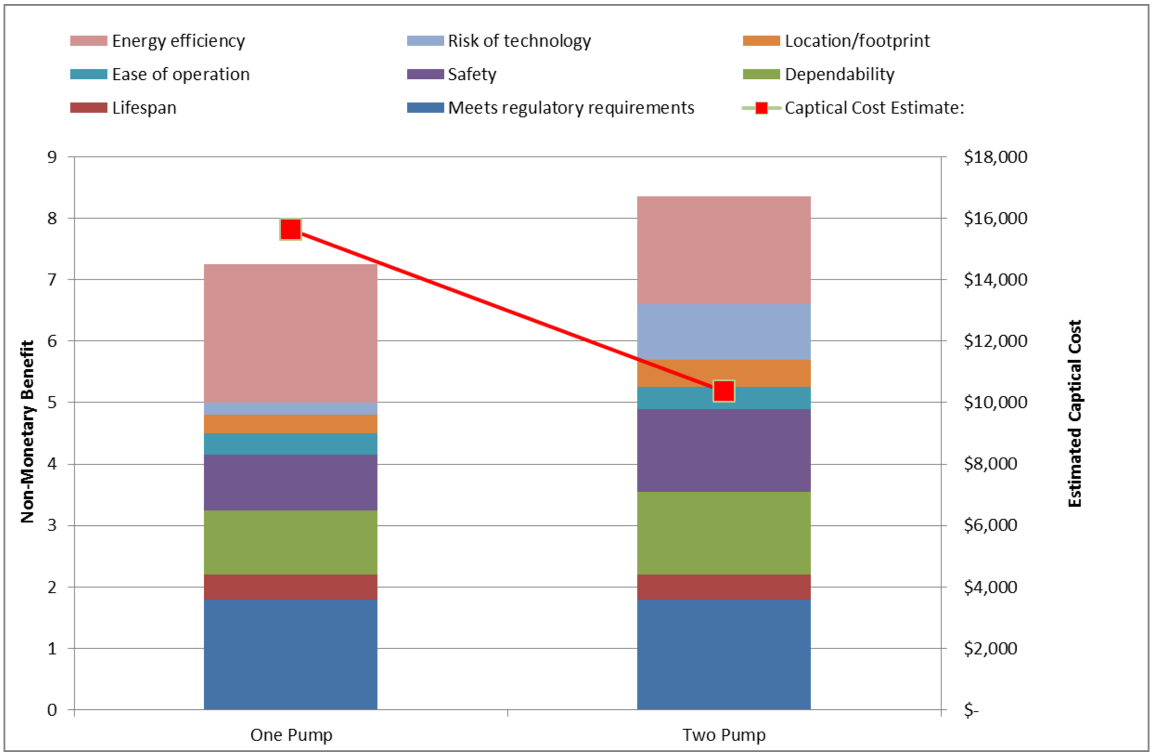


Figure 8 MCDA Figure

Meeting regulatory requirements-20%

This value corresponds to the pump system being able to provide enough amount of water for Gufu village. It also refers to making sure the system does not degrade further regulated local standards.

For this criterion, a score of 9 was given to both one pump system and two pump system, since both systems can provide enough water for Gufu village. However, one pump system requires an elevation difference, and two pump system are usually used for larger volume flow, which may not be necessary for small villages.

Lifespan-5%

Lifespan means the length of time a system can continue to process the water and meet the standards. This relates to how long the system is predicted to stay in operation.

For this criterion, both one pump system and two pump system get a score of 8.

Dependability-15%

Reliability and Dependability indicate the ability of the pump system alternatives to consistently achieve the desired effluent criteria without process upsets and malfunctions. Pump system can provide a consistent water flow rate and meet the water demand of Gufu village on all weather conditions.

For this criterion, a score of 7 was given to one pump system and a score of 9 was given to two pump system. That is because one pump system will be out of use if one pump doesn't work, while two pump system can continue work if one pump is out of use.

Safety-15%

Safety considers the risk operators experience when using the system. Safety includes moving parts and operator's duties as possible risks.

For this criterion, a score of 6 was given to one pump and a score of 9 was given of two pumps, since one pump system require a higher elevation. It will not be easy to move parts for one pump system.

Ease of operation-5%

Ease of operation is an important factor to evaluate if the design is reliably handled. It will be beneficial for operators to increase their working efficiency.

For this criterion, both one pump system and two pump system got a score of 7, since once the systems have been installed, they will both be easy to operate.

Location/footprint -5%

The design should be based on current facility locations, and the available space for expansion. The design should make the location of every step in the whole plan is rational and conserves space.

For this criterion, a score of 6 was given to one pump system and a score of 9 was given to the two pump system, since one pump system requires an elevation difference.

Energy efficiency-25%

As a developing place and a tight budget, Gufu village will depend on solar panels to provide most of electricity. Limiting energy use is a requirement according to the local condition, and is cost efficient.

For this criterion, a score of 9 is given to one pump system and a score of 7 was given to two pump system. As one pump system will have an addition head, less energy is required for one pump system comparing with two pump system.

Risk of technology -10%

This term involves how developed the technology is. If the technology is common, the risk would be low, but the risk would be high if the technology is still in the experimental phase.

For this criterion, a score of 2 was given to one pump system and a score of 9 was given to two pump system, because one pump is less used and two pump system has been widely used. There may have technology risks or accidental problems that can not be solved easily as the one pump system is not widely used yet. In this case, the two pump system will have less risk about new technology.

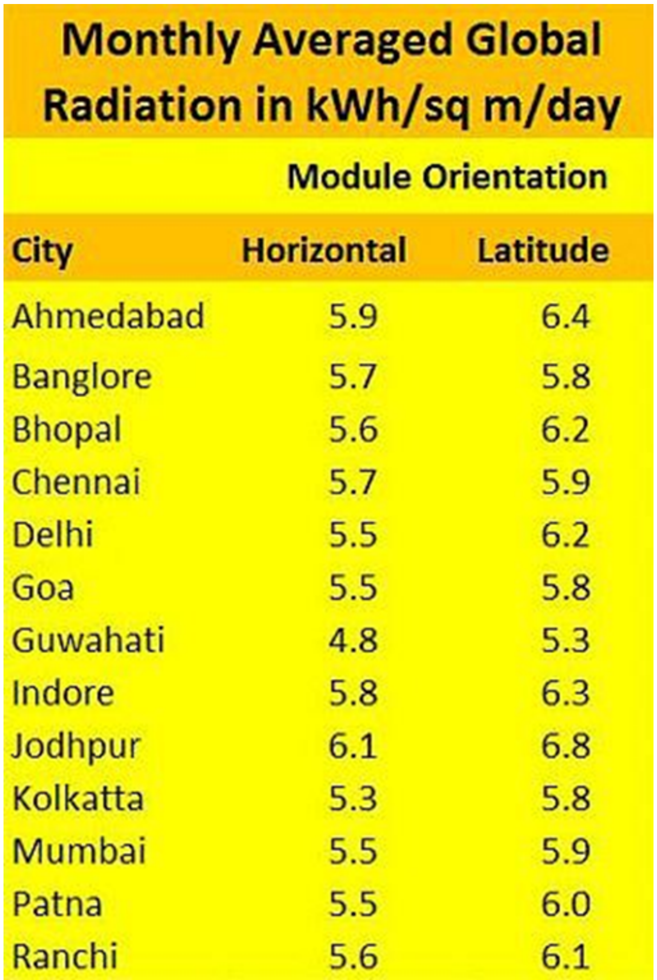
Solar Powered Pumping System

The selection of a solar powered pumping system should consider different feasibility aspects and future prospects of technology. There are several important steps in the process. The first step is to understand the reason to choose a solar powered pumping system(SPSS). For example, if the public power grid is reliable and in proximity to the site, preferably less than 1/3 mile, then solar power may be a poor choice. Based on Van Peltm et al. 2014 , Table 3 summarizes the pros and cons associated with different sources of alternative energy for groundwater pumps.

Table 3 Pros and Cons of Alternative Form of Energy for Pumps

	Pros	Cons
Generator	•Moderate initial cost •Easy to install	• High maintenance, expertise required for repair • Short life expectancy (5 years) • Fuel is usually expensive • Long term (10-20 years) annual costs to operate higher than SPSS
Wind Turbine	•Lower initial costs than SPSS •Long life expectancy •Effective at windy sites (avg. wind speed at least 10 mph) •Clean •No fuel needed	• High maintenance needs • Expensive repair • Parts difficult to find • Wind can vary seasonally and daily • Lower output in calmer winds
Solar Powered Pumping System	•Easy to install • Can be mounted on trailer to accommodate moving livestock • Reliable long life expectancy (20+ years) • Low maintenance, simple repair if related to solar array • Clean • No fuel needed • Modular system can be closely matched to needs, power easily adaptable to changing demands	• Solar energy can vary seasonally • Higher initial cost • Lower output in cloudy weather
From: "Solar Pumping Systems (SPS) Introductory and Feasibility Guide, "Green Empowerment.		

The second step is to consider the site location, which is a major part in the feasibility of a solar powered pumping system. Peak sunlight hours (PSH) are slightly different across the village. Basically, the fewer PSH available, the more expensive the photovoltaic (PV) array and pump system required. Gufu village has the coordinate of 22°55'51"N 85°7'35"E. Figure 9 shows the PSH for the main cities in India. Based on the Google map, Gufu village is close to Ranchi, which is 1 hour driving distance so this group considers the PSH is as same as Ranchi.



Monthly Averaged Global Radiation in kWh/sq m/day

	Module Orientation	
City	**Horizontal**	**Latitude**
Ahmedabad	5.9	6.4
Banglore	5.7	5.8
Bhopal	5.6	6.2
Chennai	5.7	5.9
Delhi	5.5	6.2
Goa	5.5	5.8
Guwahati	4.8	5.3
Indore	5.8	6.3
Jodhpur	6.1	6.8
Kolkatta	5.3	5.8
Mumbai	5.5	5.9
Patna	5.5	6.0
Ranchi	5.6	6.1

Figure 9 Peak Sunlight Hours in India

Most of Gufu Village has a PSH of 5.6 for modules mounted horizontally and 6.1 when the modules are mounted at the latitude angle of Ranchi which is approximately 30 degrees. The PSH used to find the flow rate is 6 hours. Another factor is the climate of the region. Solar powered systems are not typically designed for extremely cold weather (temperature less than minus 20 degrees C or minus 4 degrees F). Table 4 shows the average temperature per month for Ranchi. The coldest month is January and has approximately 8.7 degree C. The weather is above the lower limit of the solar powered system, which means the temperature won't affect the system efficiency significantly. This conclusion can also be achieved using Equation (1) to Equation (7).

Table 4 Temperature and Precipitation per Month for Ranchi

	Temperature		
Months	**Normal**	**Warmest**	**Coldest**
January	16.7°C	24.7°C	8.7°C
February	19.4°C	27.2°C	11.6°C
March	24.6°C	33.5°C	15.7°C
April	30.2°C	38.8°C	21.5°C
May	33.1°C	40.9°C	25.3°C
June	32.7°C	38.5°C	26.8°C
July	29.2°C	33.2°C	25.2°C
August	28.8°C	32.5°C	24.9°C
September	28.4°C	32.7°C	24.0°C
October	26.1°C	32.1°C	20.1°C
November	21.8°C	29.2°C	14.3°C
December	17.4°C	25.5°C	9.4°C

Assume the plant only runs 6 hours a day (PSH=6 hr), the flow rate has to be adjusted. An estimate of the required flow rate of the pump can be determined by the following equation:

$$Flow\ Rate\ (gpm) = \frac{Demand\ in\ gpd}{PSH\ per\ day} \times \frac{hr}{60\ min} \qquad \text{Equation (9)}$$

The next important step is to choose a type of cell. PV cells are primarily made from silicon and come in three different types: monocrystalline, polycrystalline (multicrystalline), and amorphous. Figure 10 shows the three types of PV configurations.

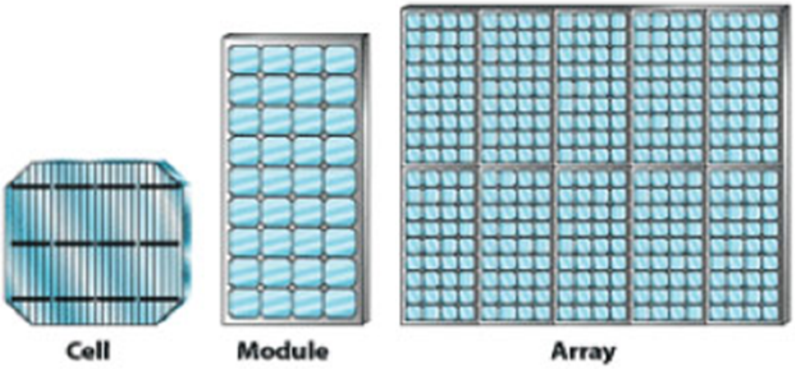


Figure 10 Types of PV Modules

The efficiency of the PV module relates to the area of active cells exposed to the sunlight. Monocrystalline are the most efficient, converting approximately 15 percent of the sun's energy to electricity, but they are also the most expensive of the three. Photovoltaic modules have typical warranties of 20 to 25 years, with life expectancies approaching 30 years. Table 5 compares the differences between the three main types of PV cells. If batteries and a regulator are added into the system, the PV array demand will be higher. The PV array needs to be mounted securely to a tilted rack that is fixed to the ground. If the modules are fixed, the orientation of the tilt is to the south and should be equal to the site latitude. If they are on an adjustable mount, the tilt should be the latitude minus 10 to 15 degrees in the summer and the latitude plus 10 to 15 degrees in the winter.

Table 5 Types of PV Cells and Their Efficiency

Type of Cell	**Efficiency Range**	**Comments**
Monocrystalline	14 to 16%	Highest price, affected by temperature
Polycrystalline	12 to 14%	Medium price, affected by temperature
Amorphous Silicon	8 to 9%	Medium to low price, not affected by temperature
Source: Research Institute for Sustainable Energy, Murdoch, Western Australia		

From the Table 5, it is obvious that the efficiency for the PV cells is really low. To increase the photovoltaic efficiency, one of the most promising developments in the laser supply market is laser doping or laser diffusion of selective emitters. This doping process is one of the main processes used. By using this method, the absolute cell efficiency will increase 0.4 to 0.5 percent.

A new technology called singlet fission has recently been discovered that could boost solar cell efficiency by 30 percent. Through this process, a single photon of light will generate two electrons instead of one. The basic concept for this technology is convert energy from coherences to kinetics. However, since the technology is new, the cost estimation still needs more research.

Calculated Values

The team calculated required pump power and solar power in order to select proper size and amount of pumps and solar panels. In this section, an estimated cost is also provided according to market price of selected pumps and solar panels. More detailed calculation process is provided in the Mathcad file.

Power needed:

The power needed is a function of the elevation, flow rate, and headloss through the distribution system. So the first step will be calculating the elevation changes. Assume the water is pumped from the well to the plant and gravity takes the water the distance to the village. The height of the plant will be the elevation of the village minus the elevation of the well and plus the head loss through the pipe. The power needed to pump water from a well at ground level to the elevated plant can be calculated. Assume every household will get the same amount of water. As an ideal situation, the flow equity will be 100%. According to goolge map, the team got Gufu village elevation and Gufu well elevation. The total headloss is from village distribution subteam.Then the required power head can be calculated as 13.368 m. Assume the pump has 45% efficiency, the power will be 698 W. The calculation process is in the attached mathcad file. In this case, the team select two pumps sizing 0.5 hp, 720 gph.

In order to make sure the selected pump can provide sufficient flow rate for the Gufu Village, the team used equation (8) to calculate flow rate that the pump system can provide. The actual flowrate will be 5.5L/s in the system, which is larger than the plant flow rate. The designed pump system can deliver enough amount of water for Gufu Village.

A total amount of power that should be supplied by the solar panels is 4.95 kW as the actual solar power output is the required pump power and the efficiency of polycrystalline solar panel is 14% according to Van Peltm. We assumed that solar panel CS6P-250P will be used in this project, which can provide 250 W power. Therefore, 20 panels will be needed.

Costs:

In order to find the cost, several things need to be considered: the cost of the pumps, inverter and the solar panels. Based on the assumption from last semester, several of the following functions are useful to calculate the cost. The cost for HBL 250 W polycrystalline solar panel CS6P-250P is $263, and for 6 kW inverter is $600. The cost for one 0.5 Hp, 720 GPH pump is $79. The total cost will be given is $6,018.

Conclusions:

The team has addressed the pre-existing work of past years in order to lay the groundwork of what ideas, designs, and information already exists for the work in Gufu Village. In this research, the team has been able to define the main variables the team will be considering and working with along with equations that will allow this group to calculate for the total volume of water pumped (meeting the daily water demand). The team knows that the existing designs can adjust around 100 liters per day for a population of 500 (5 people her household) and that the team will want to make the parameter of equity in flow between houses as small as possible. In further research the team will need to collect data to find the monthly average daily solar insolation value as well as the monthly average clearness index values of the village. In order to fulfill the energy requirement of about 700 watts, the team decided to use 20 solar panels (each providing 250 watts) in order to make up for the loss of energy due to the efficiency of each solar panel. Ultimately, the choice was made to use the two pump system rather than the one pump system due to the overall better score when comparing the different aspects of the two. After calculations, the total cost for this design would amount up to 6,018 USD.

Future Work

Future teams should research more information on peer reviewed publications, especially about actual weather conditions for the PV pump design and different characteristic between one pump system and two pump system such as pump curves, to help with the future development in the Gufu Village design project. More should be looked into about how to make the solar arrays at their most efficient for the area (for example, making plans about using an adjustable array setup or choosing a bifacial solar array) and to evaluate how to implement these changes into the system. It would also be beneficial to look into making the aforementioned designs suitable to the environmental conditions of villages of new water source, corrosion problems, pipe leakage problems as well as further general research into how effective any of these changes would be by looking into practicality and reality and thinking outside of the theoretical perspective of these plans. More research about singlet fission can also be made in future work.

References

Kelterborn, D., Levine, S., Parisi, N., & Whiteheart, R. (2014, May 16). Village Source to Environment. Retrieved September 15, 2014, from https://confluence.cornell.edu/

Solar Products. (n.d.). Retrieved October 10, 2014, from http://www.hbl.in/home

Pumps in Parallel or Serial Connection (n,d) Retrieved November 5, 2014, from http://www.engineeringtoolbox.com/pumps-parallel-serial-d_636.html

Basics of Solar PV System Design (2013, February 21) Retrieved November 5, 2014, from https://livingonsolarpower.wordpress.com/2013/02/21/basics-of-solar-pv-system-design/

Van Peltm, R., Weiner, C., and Waskom, R. Solar-powered Groundwater Pumping Systems. Retrieved November 5, 2014, from http://www.ext.colostate.edu/pubs/natres/06705.html

Than, K. "New Technology Could Boost Solar Cell Efficiency By 30 Percent." *Llancaster*. 21 July 2014. Web. 20 Nov. 2014. <http://www.insidescience.org/content/new-technology-could-boost-solar-cell-efficiency-30-percent/1816>.

"Calculate the Cost of Photovoltaic Systems (Home Solar Electricity)." *Simple PV Project*. Web. 21 Nov. 2014. <http://www.nmsea.org/Curriculum/7_12/Cost/calculate_solar_cost.htm>.

Lim, Yun Seng, Chin Kim, Shin Yiing Kee, Hong Tat Ewe, Abd Rahman Faidz. "Design and evaluation of passive concentrator and

reflector systems for bifacial solar panel on a highly cloudy region – A

case study in Malaysia." Renewable Energy 63.March (2014): n. pag. EBSCO

Host. Web. 12 Nov. 2014.