DEVELOPING A SITE-APPROPRIATE SOLAR-ELECTRIC POWERED WATER PUMPING SYSTEM

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family

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of the University of Florida in Partial Fulfillment of the
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DEVELOPING A SITE-APPROPRIATE SOLAR-ELECTRIC POWERED WATER PUMPING SYSTEM

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Solar-electric power has been used as a water distribution method in many parts of the world. This alternate is competitive to diesel and petroleum-powered options where there is ample solar resource, moderate demand and no access to the electric grid. This study investigated the use of solar-electric powered water pumping in remote areas. A literature review was conducted, and from this a criteria of the following six critical success factors was formed: 1) technical practicality, 2) economic feasibility, 3) environmental impact, 4) socio-cultural appropriateness, 5) adaptability and 6) resiliency. Previous solar-electric powered water pumping projects were reviewed and analyzed based on these critical success factors.

A solar-electric powered water pumping project was planned for a selected site in rural Western Kenya. Data on site solar insolation was gathered by conducting a PV-Watts analysis, calculations for implementation were conducted and price quotes were collected. A life-cycle cost (LCC) analysis was conducted to compare the solar-electric powered water pumping option to that of a petroleum-electric powered water pumping

system. The amount of carbon dioxide (CO_2) emissions from using the petroleum-electric powered water pumping system was calculated. From this information, the six critical success factors were applied for the recommendation of a solution for the particular site.

This study determined that implementing solar-electric powered water pumping systems that apply the six critical success factors would be more successful. For the selected site in Kenya, it was found that its location near the equator would provide uniform solar intensity throughout the year. The life-cycle cost analysis found that for the given site, a solar-electric powered water pumping system would break even in price within only one year when compared to the existing petroleum-electric powered water pumping system over a 20-year period. This study also found that using the existing petroleum-electric powered water pumping system to pump the daily water demand would result in the release of over 23 metric tons of CO_2 per year.

CHAPTER 1
INTRODUCTION

In many arid countries rainfall is decreasing, making surface water scarce (Argaw 2006). This has increased the demand for groundwater, but the water table is also decreasing. Due to this, manual pumping has become more difficult. Diesel, petroleum, kerosene and windmills have traditionally been used to pump water from deeper levels, but solar photovoltaic and wind turbine pumps are becoming more common. In the rural areas of East Africa's Arid and Semi-Arid Lands (ASALs), women and children may spend up to eight hours a day collecting water (UN 1997). This reduces their time spent in school or earning an income (Ray 2007). Additionally, this results in adverse health effects due lack of access and transporting water daily (Ray 2007), and puts girls and women at risk for harassment (Short and Thompson 2003). In response to this, several non-governmental organizations (NGOs) and religious groups have installed boreholes. While these efforts have greatly increased the quality of life for some rural villagers, many people still must travel great distances to obtain water and carry it home.

Previous research conducted found that solar power in rural areas of the ASALs would be a viable option for water supply. The following reasons support this:

- Kenya lies within moderately favorable solar resource due to location within 15 degrees of the equator resulting in a uniform solar intensity throughout the year. (Acra et al. 1990).
- Since 1976, costs have dropped about 20 percent for each doubling of installed photovoltaic (PV) capacity, or about five percent per year (Fischlowitz-Roberts 2002).
- PV sources of electricity are most competitive where small amounts of energy are required in areas far from the grid (Markvart 2000).

Research Aim and Objectives

The aim of this thesis is to investigate the feasibility of implementing PV-based water pumping system for domestic water use within the context of developing country. Specific objectives are as follows:

1. To critique existing solar-electric powered water pumping systems
2. To develop critical success factors for a solar-based water pumping system
3. To assess the feasibility of a proposed system using the specifications for a selected use case

Contributions

This research contributes to on-going studies related to the development of sustainable water infrastructure systems in the third world. The findings of this thesis are intended to benefit a specific site in Kenya. Additionally, it provides an example of solar-electric powered water pumping used for irrigation benefiting rural areas of the United States. Lastly, the state of Florida is located in a favorable location for solar resource, and the methodology used to determine suitability of a solar-electric powered water pumping system could be used to benefit the planning of various solar-based projects within the state. Overall, the guidelines developed for critical success factors are applicable to the planning of a solar energy project anywhere in the world.

Hypothesis

The following hypothesis was adopted for the study:

Solar-based water pumping projects will be economically competitive when compared to other options. Given the appropriate climate, this technology will be applicable anywhere.

Limitations on Research

There are many important aspects to further investigate in water infrastructure for developing countries including the design of structural materials for water storage, purification and distribution. However, this thesis will focus on water distribution, specifically in the form of solar power.

Guide to the Rest of the Thesis

Chapter 2 presents a literature review on the technical, economic, environmental and socio-economic success factors of solar-electric powered water pumping systems. Additionally, it provides a review of some case studies.

Chapter 3 is the Methodology, consisting of aims and objectives, a timeline, site selection and an assessment for the proposed solar-electric powered water pumping system compared to other options. Chapter 4 provides results of the methodology and Chapter 5 provides a discussion. Chapter 6 concludes the research and Chapter 7 provides recommendations for further investigation.

CHAPTER 2
LITERATURE REVIEW

Worldwide, there are over 10,000 solar-electric powered water pumps installed to provide villages with water from boreholes, wells, rivers and canals (Markvart 2000). A solar-electric powered water pumping system uses a photovoltaic (PV) array that powers an electrical motor which operates a pump. The water is pumped into an elevated storage tank. This converts the energy from the PV array into potential energy, eliminating the need for battery storage of the generated electricity. Figure 2-1 illustrates this process.

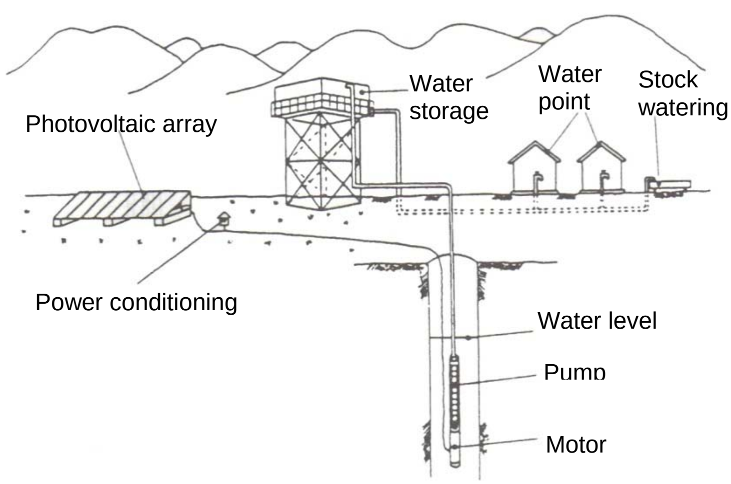


Figure 2-1. Solar-electric powered village water supply

Source: Markvart 2000

Many solar-electric pumping systems are powered by wind generators or photovoltaic arrays; however, solar pumps are best suited for small villages of 100 to 1,000 people and moderate agricultural uses (Ghoneim 2006). PV is preferable where there is ample solar resource, moderate demand and no access to the electric grid. Stand alone photovoltaic systems (as opposed to grid-connected systems) often rely on a set of back-up batteries for night time and outages (Ghoneim 2006). Solar energy is ideal for water pumping as the water requirement tends to peak during hot weather periods when solar radiation intensity is high, resulting in maximum array output (Ghoneim 2006). Similarly, the water requirement decreases during cooler weather when the sunlight is less intense.

This literature review provides an overview of the current research and case studies available on the use of solar-power for water pumping. It is divided into the following sections: Contextual Background, Critical success factors (Technical, Economic, Environmental / Ecological, Socio-Cultural, Adaptability and Resilience), Case Studies and a Summary.

Contextual Background

In 1976, the NASA Lewis Research Center began installing 83 photovoltaic power systems on every continent except Australia, which provided electricity for many different applications including water pumping (U.S. DOE nd). In 1978, the center installed the world's first village PV system on the Papago Indian Reservation of Southern Arizona (USA). The 3.5-kilowatt PV system was used to pump water and provide electricity for 15 houses until 1983 when the community was connected to the electric grid. The PV system was then solely dedicated for water pumping from a well.

Critical Success Factors

Many aspects are to be considered when planning for a solar-electric powered water pumping system. These include, but are not limited to: technical, economic, environmental / ecological and socio-cultural factors.

Technical

While manual pumping has been the most common supply method in rural areas, there are many disadvantages to this including regular maintenance and attendance. Additionally, this method can only be used where small volumes are required at low or moderate pumping heights (Ghoneim 2006).

There are many advantages to using PV for water pumping, including the fact that it is a reliable technology, requires little maintenance, is easy to install, and is proportional in terms of power generated and water demand (Ghoneim 2006). The system can be equipped with storage tanks instead of back-up batteries to supply water at night or during cloudy periods and the water can be used for household and irrigation needs (Ghoneim 2006).

The main components to a solar-electric powered water pumping system include the PV array, the pump, the pump-motor and the controller. There are three main categories of solar cells: monocrystalline at 17 percent efficiency, polycrystalline at 15 percent and amorphous at seven percent (Meah, et al. 2008).

In selecting a pump for this system, the main factors to consider include water requirement, water height and water quality (Meah, et al. 2008). Currently available motor types include AC, DC, permanent magnet, brushed, brushless, synchronous and asynchronous, variable reluctance, and others.

There are five types of pumps to which can be used in solar water pumping systems (Markvart, 2000):

1. Submerged multistage centrifugal motor pump sets (Figure 2-2A) are the most common. They are easy to install and the motor pump set is submerged away from potential damage.

2. Submerged pumps with surface mounted motors (Figure 2-2B) were common in Sahlelian West Africa in the 1970s. This configuration provides easy access to the motor, but submersible motors have become more common over the years.

3. Reciprocating positive displacement pumps (Figure 2-2C) are suitable for high-head, low flow applications where they are often more efficient than centrifugal pumps.

4. Floating motor pump sets (Figure 2-2D) are ideal for irrigation pumping from canals and open wells.

5. Surface water pump sets (Figure 2-2E) can only be used when an operator is always present.

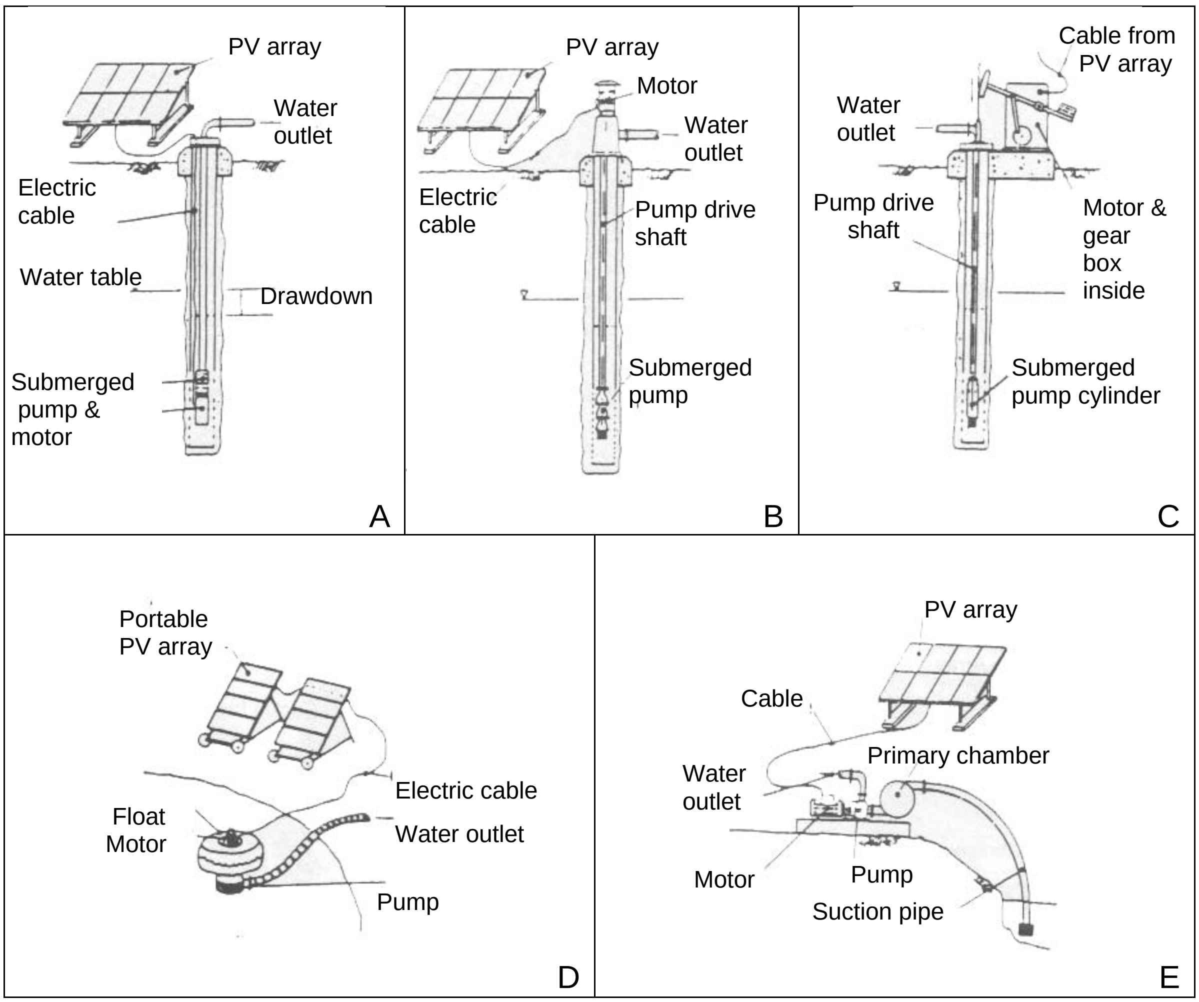


Figure 2-2. Series of pump sets. A) submerged multistage centrifugal motor, B) submerged pump with surface mounted motor, C) reciprocating positive displacement pump, D) floating motor pump set and E) surface water pump set

Source: Markvart 2000

Pump sizing requires three basic pieces of information: water requirement (m3/day), total water head and continuous water flow or recharge rate of the well (Meah, et.al 2008). Cloudy days should be considered by allowing for five percent over design of the pump.

The two main types of pumps that are used in conjunction with photovoltaic panels (PVPs) are centrifugal and positive displacement, as seen in Figures 2-2A and 2-2C (Short and Thompson 2003). Centrifugal pumps use high speed rotation of an impeller to suck water in through the middle pump, throwing water out at the edge. Positive displacement pumps transfers discrete packets of water by a primary mover. The high cost of PV panels, often leads to the selection of the lowest costing pump, which is usually the centrifugal. However, it is more recently believed that positive displacement piston pumps using the induced flow principle are more effective in that they are able to pump over a wide range of heads. This differs from the centrifugal pump, which is very site-specific. Conversely, neither pump is currently designed to work at Village Level Operation and Maintenance (VLOM) (Short and Thompson 2003).

Village Level Operation and Maintenance (VLOM)

Village level operation and maintenance (VLOM) refers to the capability of a village to have the aptitude to maintain and repair equipment (Short and Thompson 2003). This level may vary regionally or nationally. For example, some hand pumps have maintenance demands similar to that of bicycle repair. In a village where bicycles are common, skilled bike repair mechanics are likely available; whereas, in a village where bicycles are not common, skilled mechanics may be scarce.

Thus, the technology must be appropriate for the selected context. The principle aims of ‘appropriate technology’ for sustainable development include the following (Dunn 1978):

1. To improve the quality of life of the people.
2. To maximize the use of renewable resources.
3. To create work places where the people now live

These goals can be achieved by incorporating the following criteria (Dunn 1978):

4. Employ local skills.
5. Employ local material resources.
6. Employ local financial resources.
7. Be compatible with local culture and practices.
8. Satisfy local wishes and needs.

Failure to comply with the five criteria may result in an unsustainable project. A photovoltaic water pumping system manufactured at village level would use local skills and local materials, and would therefore result in a more sustainable end product in which the community would have confidence in the VLOM.

Economic Factors

Most PV systems are designed in developed countries where cost is the main concern (Short & Thompson 2003). Components to plan for include the solar panels, the water pump, storage tank and distribution piping. The solar panels and the pump are contingent upon one another. As the efficiency of the pump system is improved, the number of PV panels can be reduced. This maximizes the water output, while decreasing the cost of the technology. The same can be said for pipe lines. A one kilometer distribution line extension costs between US $10,000 and US $16,000, but a complete small-scale solar water pumping system costs only $3,000 to $10,000 (Meah et.al. 2008). The fact that solar water pumping systems do not require battery backup, makes them maintenance free and reduces the complexity and capital costs (Meah et al. 2008).

Life Cycle Cost (LCC)

The life-cycle cost (LCC) analysis can be used to compare a PV water pumping system to other options such as diesel or wind powered systems. This involves calculating all estimated project costs over a specified period to the present value. The LCC calculation is as outlined by (ASTM E 917-89):

$$PVLCC = IC + PVM + PVR + PVF - PVS \tag{2-1}$$

Where:

PVLCC = Present Value Life-Cycle Cost

IC = Initial Cost

PVM = Present Value Maintenance and Repairs

PVR = Present Value Replacements

PVF = Present Value Fuel

PVS = Present Value Salvage

Maintenance costs are constant over time and need to be converted to present value. This can be calculated using the following (Ruegg and Marshall 1990):

$$P = A\left[\frac{(1 + D)^n - 1}{D(1 + D)^n}\right] \tag{2-2}$$

Where:

P = Present Value

A = Annual Amount

D = Discount Rate

n = Number of Years

Future estimated replacement costs and salvage value need to be converted to present value by (Ruegg and Marshall 1992)

$$P = \frac{F}{(1+D)^n} \tag{2-3}$$

Fuel costs need to be converted to present value by (Ruegg and Marshall 1992)

$$P = A_O \left[\left(\frac{1+E}{1-D}\right)\left(1-\left(\frac{1+E}{1+D}\right)^n\right)\right] \tag{2-4}$$

Where:

P = Present value

A_O = Initial value of a periodic amount which occurs over *n* periods

E = Constant periodic rate of change (escalation)

P = Present value

D = Discount rate

n = Number of periods

Environmental / Ecological

In many arid countries rainfall is decreasing, making surface water scarce (Argaw 2006). This has increased the demand for groundwater, but the water table is also decreasing. Due to this, manual pumping has become more difficult. Diesel, petroleum, kerosene and windmills have traditionally been used to pump water from deeper levels, but solar photovoltaic and wind turbine pumps are becoming more common. These renewable resources are ideal for rural applications off of the electric grid where fuel source is unreliable and repairpersons are scarce. Solar is a clean and renewable source, as its utilization produces no greenhouse gases or hazardous wastes (Ghoneim 2006).

Socio-Cultural

One major concern associated with water and development is the issue of gender. In many developing countries, women and children are primarily responsible for the provision of domestic water (Ray 2007). This reduces the time spent in school or earning an income. The chore also has adverse health effects due lack of access and transporting water daily (Ray 2007), and puts the girls and women at risk for harassment (Short and Thompson 2003).

Another socio-cultural factor in the installation of a solar-electric powered water pumping system is that of theft and vandalism. This can be prevented through hiring security guards, installing surveillance cameras or keeping the equipment out of reach. Boreholes can have a lockbox installed to protect the pump and panels can be surrounded by a fence with barbwire at the top. Oftentimes, solar panels are soldered to roofs, mounted on top of water tanks or installed above steel poles. This is also ideal for meeting space constraints; however, locating the panels up high makes cleaning more difficult. Dusty panels can result in an inefficiency of 20-30 percent (Center for Alternative Technologies meeting, 2010). Although this was made known, some clients of the Center for Alternative Technologies in Kenya have opted to install solar panels out of reach, due to more pressing concerns of theft.

Case Studies

Solar-electric powered water pumping systems of various scales have been researched and implemented in different parts of the world. The following case studies summarize some of these projects.

Guatemala Orphanage: Back-Up Source at Existing Well

Civil engineering students from Marquette University designed and implemented a solar powered water pumping system for the Santa Maria de Guadalupe Orphanage in Guatemala. The project site was approximately located at 14.79 latitude and −90.97 longitude and was 2,200m above sea level (Borg and Zitomer 2008). Solar resource at this location is estimated to be 5 kWh/m^2/day (UNEP, 2005). The site was relying on water from two sources: a municipal supply and an existing well on site. The existing pre-cast concrete well was 15m deep, had a capacity of 7,000L, and pumped water approximately 24m above ground. This pump was powered by an electric utility provider, but the supply was unreliable. The solar water pump system was expected to increase reliability, while decreasing operating costs. The water storage tank and construction site are shown in Figures 2-3A and 2-3B.

A positive displacement-piston cylinder water pump powered by a direct current (DC) motor was selected because of its simplicity in installation, high flow rate, high head required and durability. Due to potential energy provided by the elevated tank, the system did not require inverter or battery storage. The new pumping system supplied 76L of water per person per day for a population that was expected to increase from 90 to 140 people over the next 20 years. These specifications exceeded the World Health Organization’s minimum requirements of 20L per person per day from a source within one kilometer of the person’s dwelling (WHO 2008). The design flow rate was approximately 36.4L/min. The pipe system consisted of 320m of five-centimeter PVC pipe. For this flow rate, losses were estimated to be 0.12 to 0.58m.

A B

Figure 2-3. Series of images from installation at orphanage. A) storage tank and B) construction site

Source: Borg and Zitomer, 2008

Overall, the equipment cost was $4,486 USD. This included solar panels, a pump, pump switches, valve, linear current booster, pipes and fittings. The team assembled this system in the United States and shipped it to Guatemala. The Marquette team worked on a limited scope, in that the solar pumping system would only provide some of the water and the pumping distance was within the property of the orphanage. In doing this, the team was able to fulfill their objectives, and the project could serve as a pilot for more involving future projects.

Mvuleni Village, Tanzania: Large-Scale Village Supply

A non-profit organization constructed a solar-electric powered water pumping system, shown in Figures 2-4A and 2-4B, from two existing boreholes in Mvuleni

Village, which is in the Moshi District of Tanzania’s Kilimanjaro Region. The project site was located at a longitude of 037’23.550 E and latitude of 03’17.200 S. In 2003, this village had an estimated population of 6,893 and 1,416 houses (Mvuleni Water Project 2006). Many residents walked three kilometers to fetch contaminated water from the nearest spring.

A B

Figure 2-4. Series of photos from Mvuleni project. A) solar panels and pipes and B) solar panels

Source: URL 1

Initially, the main constraint was finances. This was addressed by encouraging each villager to contribute US $2.00 and sponsorship from Sweden. Equipment was imported from Germany through Kenya. A total of 4,800m was excavated for piping. Over 20 tap connections were installed, a water pump house was built, a hand pump was constructed and installed in one borehole, 20 towers were constructed and water storage tanks were installed. The water pumps were custom built to be powered by solar energy from the 32 solar panels with a total area of nearly 30sq m. The solar panels were mounted on a solar tracker that follows the sun for optimal efficiency. The water is pumped to the center of the village approximately 2,000m through 110 mm plastic pipes. From this location, the water is then pumped to plastic water tanks using 50 and 63 mm pipes. The final project cost was US $53,400, which was almost US $6,000 more than anticipated.

University of Wyoming Motor Testing and Training Center: Rural Irrigation

A solar water pumping initiative was started at the University of Wyoming Motor Testing and Training Center (UWMTTC) to supply ground water for irrigation purposes to Wyoming's rural ranches where long-term drought has tended to impact surface water more severely than ground water. This project investigated the technical, environmental and economic benefits of using solar over electrical utility or a generator. Special attention was paid to local level operation and maintenance, and some of the goals to facilitate this included (a) modifying the system based on local materials, (b) using materials from local suppliers and (c) educating people through the workshop, training and demonstration. It compared carbon dioxide emissions of coal, diesel and natural gas options used for generating 1000W over a 25-year period. In a life-cycle analysis solar-electric powered water pumping was found to be the most cost-effective and pay back at eight years.

Many of the PV panels were installed on trailers to be used at multiple water source locations, as shown in Figure 2-5. Appropriate gaps between the solar panels were to be provided to prevent wind loading from becoming an issue, and at each site, the array was adjusted according to the azimuth throughout the year. The program also evaluated systems that were one, five and fifteen year(s) old. At fifteen years, seven systems were surveyed to evaluate performance. All of the systems were still operating, although eleven replacements had been done. The pump/motor was determined to be the most vulnerable component of the system. Overall, the ranchers were satisfied with these pumping systems. Some were even able to add more livestock, due to the efficiency of the solar-electric powered water pumping system. The UWMTTC initiative has installed 88 solar-electric powered pumping systems statewide, and has recognized that this technology could be applied at similar sites in other states.

Figure 2-5. Solar panel on trailer to be used at multiple boreholes

Source: Meah, et al. 2008

Kyeleni Heath Centre and the Primary School: Small-Scale Village Supply

Global company, Nov Mono teamed up with African non-government organization (NGO) Water for All to install a 'Fun Pump' solar-electric powered water pumping system (Shown in Figures 2-6A and 2-6B) in the Kyeleni community 100 km outside Nairobi. The pump is located between the Kyeleni Heath Centre and the Primary School. The community has approximately 7,000 residents and their main source of water had been the nearby Athi River and shallow hand dug wells. The 160-watt solar panel can pump 5,000 liters of water per day from a borehole; however, when children play on the systems' integrated merry-go-round, the efficiency increases by 20 percent. This solar-electric powered water pumping system has two taps and serves local residents, as well as the clinic and the school of 1,200 students and 17 teachers. Previously, the school relied on rainwater harvesting, which was effective during only three months of the year. Since the installation of the system, the clinic has observed a decrease in waterborne diseases such as typhoid, ringworm and diarrhea.

A

B

Figure 2-6. Series of Kyeleni project images. A) solar water pumping system and B) merry-go-round

Source: URL 2

Kuwait: Computer Simulation Program

A computer simulation program was developed to evaluate the performance of a long term photovoltaic water pumping system in the Kuwait climate. This program takes into account the solar array, motor, pump, storage tank and a maximum power point tracker (MPPT). This proved to be accurate when compared to the manufacturer's program. It was determined that head height was an important factor in the economic feasibility of solar-electric powered water pumping projects. Using this computer simulation program, it was also found that there was no significant difference in system performance for panels within tilted 20 degrees of latitude.

A life-cycle cost analysis was conducted for the Kuwait region comparing a solar-electric powered water pumping system to one powered by a diesel electric generator. This system would serve domestic water from a deep well to 300 people at 40 liters per person per day or 12m^3. Even with diesel prices as low as US $0.30 per liter, the solar-electric powered water pumping system was still determined to be the most cost-effective. The findings of this study could be used to encourage nations to choose sustainable solar energy systems over conventional methods.

Jordan

Ten potential sites in Jordan were considered for solar water pumping systems, in lieu of the common pumps powered using diesel. Jordan is located between 29° 11' N and 33° 22' N, and between 34° 19' E and 39° 18 E. The city locations are shown in Figure 2-7. The country's average annual rainfall ranges from under 50 mm in the north to 600 mm in the south (Hrayshat and Al-Soud 2004). Eighty percent of this rainfall occurs in December through March. The combination of low annual rainfall and seasonal drought classifies over 80 percent of Jordan as arid.

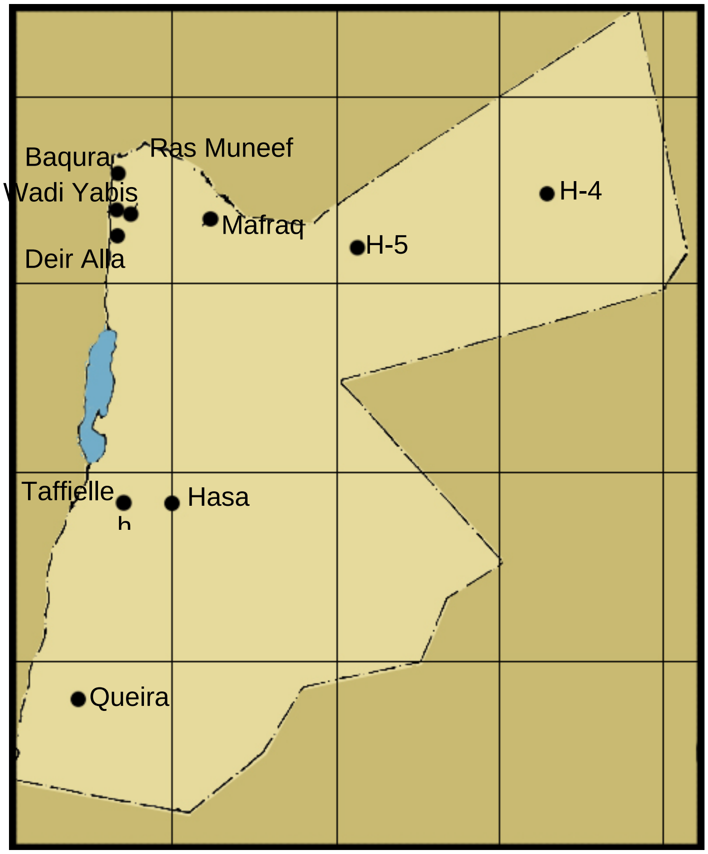


Figure 2-7. Map of 10 sites in Jordan

Source: Adapted from Hrayshat and Al-Soud 2004

Data on solar irradiance was collected for each city. The annual average for all the cities ranged between five and seven kWh/m^2/day. The average low was between two to five kWh/m^2/day in December through January, and the average high was between six and nine kWh/m^2/day during May through July. The ten cities were categorized into three groups according to their average solar irradiance: “adequate”, “promising” and “poor”. It was estimated that the four cities categorized as “adequate” would produce 62 percent of water pumped from all locations. The predicted annual water output (pumping at a height of 20 m) for each location is shown in Figure 2-8. It was determined that the solar radiation for the cities Deir Alla, Baqura and Wadi Yabis would not result in a sufficient water output. Therefore, other water pumping options would need to be considered.

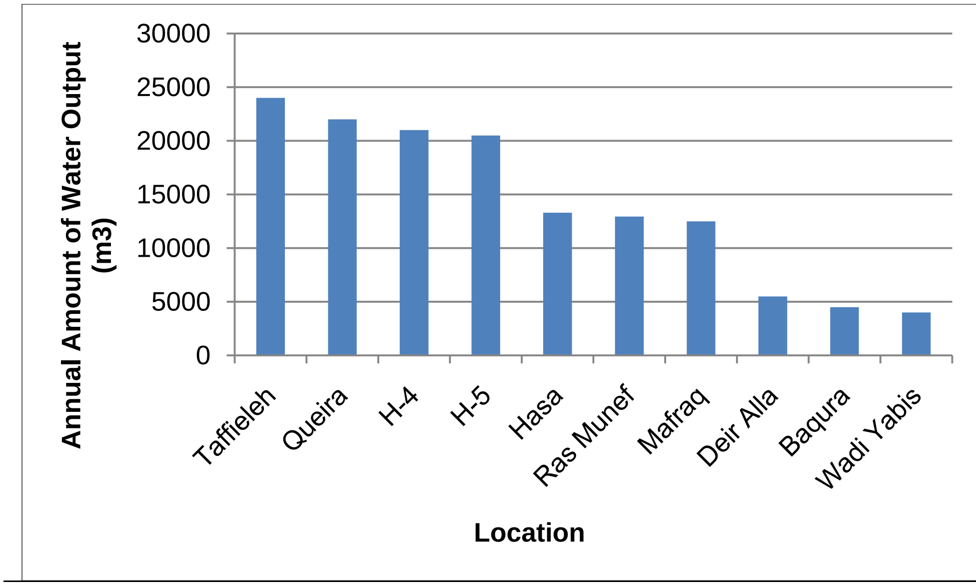


Figure 2-8. Annual water output

Source: Adapted from Hrayshat and Al-Soud 2004

Literature Review Summary

Solar-electric powered water pumping has been effective in many cases throughout the world. When planning a project the following success factors should be considered: technical practicality (including VLOM), economic feasibility, environmental / ecological impact, socio-cultural appropriateness, adaptability and resiliency. Six unique case studies were reviewed. These case studies showed that the use of this technology can vary in scale and can be used for human or livestock consumption. The systems can be designed to be portable, as in the Wyoming study, or can serve other functions that increase efficiency, as in the Kyeleni project. In each instance some, but not all of the critical success factors are known to have been applied. In an ideal system, all critical success factors should be considered. The methodology section of this thesis applied these criteria to recommend a solar electric powered water pumping system for a selected site in Kenya.

CHAPTER 3
METHODOLOGY

Solar-electric powered water pumping systems can be an effective means of water supply. The Literature Review presented cases from different parts of the world where the research and / or implementation of these systems focused on some, but not all of the following critical success factors: Technical Practicality, Village-Level Operation and Maintenance (VLOM), Economic, Environmental and Socio-cultural Appropriateness. The research activities outlined here were designed for a case study approach to facilitate an in depth investigation of the feasibility of implementing a system at a specific site in Kenya.

Aim and Objectives

The overall aim of this thesis, as stated in Chapter 1, was to investigate the feasibility of implementing PV-based water pumping system for domestic water use within the context of developing country. Specific objectives and subsequent research tasks were as follows:

1. To critique existing solar-electric powered water pumping systems
    - Case studies of previous projects were reviewed in terms of technical, economic, environmental, socio-cultural appropriateness, adaptability and resiliency.
2. To develop critical success factors for a solar-based water pumping system
    - Data on site solar insolation was gathered by conducting a PV-Watts analysis.
    - Required hydraulic power and solar array were calculated for the specific location.
    - A Life Cycle Cost (LCC) Analysis was conducted to compare solar-electric powered water pumping to that of petroleum-electric powered water pumping.

- Calculations were conducted to determine the amount of carbon dioxide emissions from the petroleum-electric powered alternate.

3. To assess the feasibility of a proposed system using the specifications for a selected use case

   - Price quotes were collected, analyzed and a recommendation was made.

Timeline

The timeline in Figure 3-1 shows the research objectives that took place over the duration of the research. A literature review took place January through March 2010 and was followed by the development of the methodology. The site was selected prior to departure for Kenya. From the site selection, geographic information was gathered and economic and environmental impacts were calculated. Research abroad took place over a 10-week period from May through July, and meetings with representatives of solar installation companies were held. Upon returning to the U.S., findings were summarized and documented.

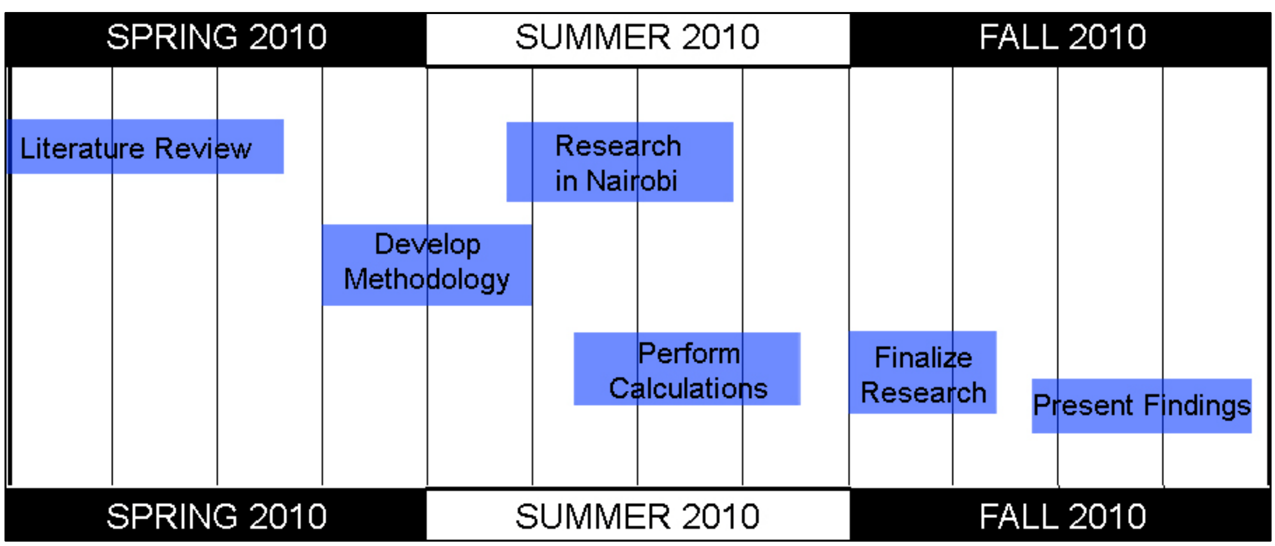


Figure 3-1. Timeline of research activities

Site Selection

The site considered was the Nyangajo Girls Secondary School in the Rachuonyo District. The nearest town is Kendu Bay (Figure 3-2). Approximate coordinates are 0° 24' 13" South and 34° 39' 0" East. The school's elevation ranges from 1,186 to 1,204m. The school has 450 students. The school is not connected to the country's utility grid. The school has used rainwater harvesting in the past, but has not done this for the last two to three years due to a leak in the concrete reservoir. The school has a 70m deep borehole, which uses a petroleum-electric powered generator to pump water into a 15,000L tank 150m away. These are shown in the school plan in Figure 3-3. The change in elevation between the ground surface of the borehole and the ground surface of the water tank is 15.24m. Additionally, there is a 5,000L overflow tank connected to the 15,000L tank that fills once the 15,000L tank is three quarters full. The school intended to sell some of this water to the community.

This system was installed in May 2010. There had been some issues with the compatibility between the pump and generator, and since the original pump was replaced and the generator was repaired, the system had only been used once as of July 2010. This is partly due to the high cost of petroleum. Fuel required for the electric pump powered by a petroleum generator to fill the $15m^3$ water tank costs 2,000Ksh. It takes eight hours to fill the water tank. Nyangajo School is currently using the pumped water primarily for cooking and drinking. For bathing and washing clothes, the students fetch water from the nearby Awach Kibuo River using buckets. There is a small generator house located adjacent to the pump, as shown in Figure 3-3. It has a roof pitch of approximately 7/12 and has east- and west-facing slopes. However, much of the northeast side is shaded by a tree and the structure is most likely too small to support solar panels for this project.

The feasibility of using a solar-electric powered system was determined. The borehole has a limit of $20m^3$ of water extracted per day. This quantity was used for the daily water demand. With a population of about 500, this is 40L per person per day. This exceeds the World Health Organization’s minimum requirement of 20L per person per day for basic access (Howard and Bartram 2003).

Figure 3-2. Exemplary deployment context

Source: Adapted from Kendu Bay Map (1963)

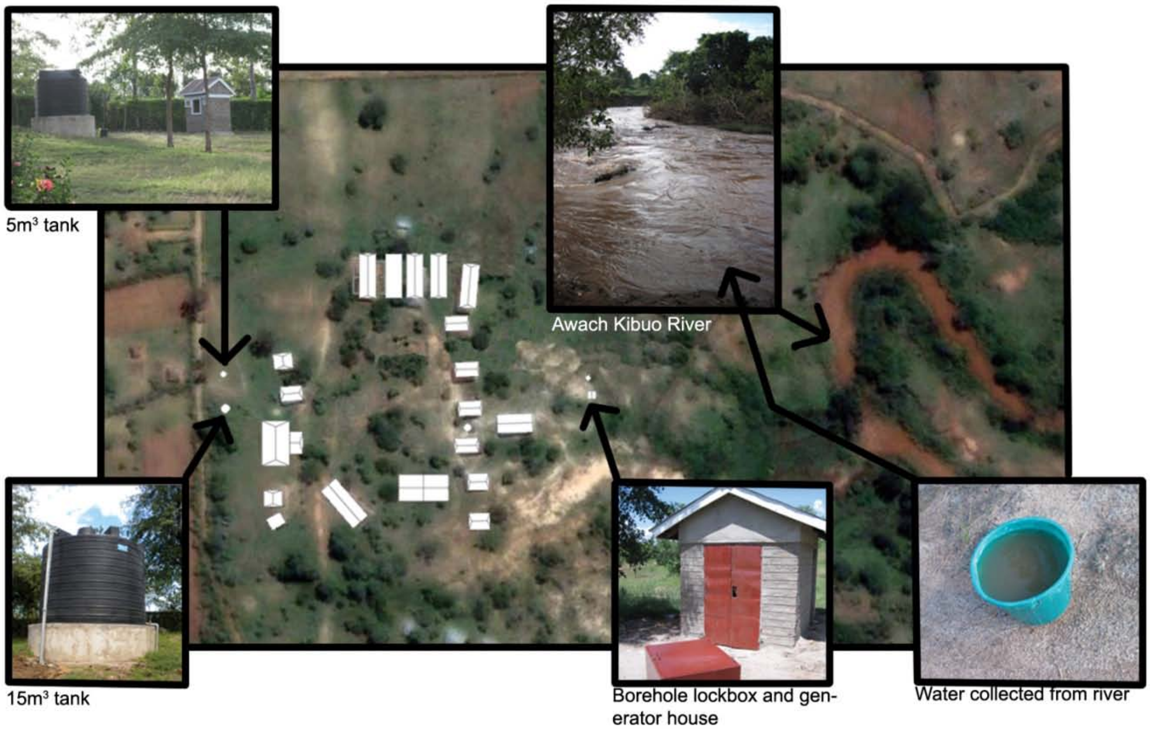


Figure 3-3. Nyangajo school site plan

Upon meeting with the principal and vice principal of Nyangajo Girls Secondary School, it was noted that the issues of water and recruitment of students were the two most important concerns. Notes from this site visit have been enclosed in Appendix A.

Assessment

Site Solar Insulation

PV-Watts is a calculator provided by the National Renewable Energy Laboratory that determines the energy production for proposed PV systems throughout the world (NREL, 2010). Using this resource, an analysis was conducted to find the available solar insolation at the site. Data for Kendu Bay is not available from PV-Watts, so nearby towns or those with similar climates where used for the analysis. Kisii, Kakamega, Kisumu and Makindu were used to collect data. The locations of these towns are shown in Figure 3-4. Additionally, various angles representing typical roof pitches were compared to that of the latitude angle (the optimum angle) to determine if using a typical roof slope would make any difference in the effectiveness of the solar-electric powered pumping system. PV system specifications are assumed to have a DC rating of 4.0 kW and DC to AC derate factor of 0.77.

Kisii town is 47 km south of Kendu Bay. The coordinates for Kisii are 0.67°S and 34.78°E with an elevation of 1,493 m. Based on the Kisii location, the ideal array tilt would be 0.67 degrees and face north at zero degrees.

Kakamega is about 100 km across Lake Victoria and northeast of Kendu Bay. Its coordinates are 0.28°N and 34.78°E with an elevation of 1,530 m. Based on this location, the ideal array tilt would be 0.28 degrees and face south at zero degrees.

Kisumu is approximately 50 km across Lake Victoria and northeast of Kendu Bay. Its coordinates are 0.10°S and 34.75°E with an elevation of 1,146 m. Based on this location, the ideal array tilt would be 0.10 degrees and face north at zero degrees.

Makindu is far from Kendu Bay (520 km) in the Southeastern Savannahs, but has a similar climate. Its coordinates are 2.28°S and 37.83°E with an elevation of 1,000 m. The ideal array tilt would be 2.28 degrees and face north at zero degrees.

Figure 3-4. Towns in Kenya selected for PV-Watts analysis

Calculations for Implementation

Hydraulic energy and the subsequent solar array power required were calculated using the following formulas (Markvart 2000):

(3-1)

$$Hydraulic\ Energy\ (kWh/day) =$$
$$Volume\ required\ (m^3/day)\ x\ head\ (m)\ x\ water\ density\ (kg/m^3)\ x\ gravity\ (m/s^2)$$

Using a water density of 1,000 kg/m^3 with gravity at 9.8 m/s^2 and a conversion factor of one Joule to 2.78 x 10^{-7} kWh, the hydraulic energy equation can be reduced as follows:

(3-2)

$$Hydraulic\ Energy\ (kWh/day) = 0.0027\ x\ Volume\ required\ (m^3/day)\ x\ head(m)$$

Where:

(3-3)

$$Head(m) = Drawdown + Tank\ height + Static\ water\ table + \Delta\ elevation\ from\ tank\ to\ well$$

Required solar array power is calculated as follows (Markvart 2000)

(3-4)

$$Solar\ array\ power\ required, peak\ kilowatts\ (kWp) = \frac{Hydraulic\ energy\ required(kWh/day)}{Average\ daily\ solar\ irradiation(kWh/m^2/day)\ x\ F\ x\ E}$$

Where:

F = array mismatch factor, 0.85 average

E = daily subsystem efficiency

Life Cycle Cost Analysis

Price quotes and equipment specifications were collected from two different solar companies in Nairobi. These were compared and then used to determine the ‘break-even’ point at which solar-electric powered water pumping surpasses the petroleum-electric powered generator as more cost-effective. A life cycle cost (LCC) analysis was conducted over a 20-year period to compare present-day costs of solar-power to that of the petroleum generator option. Equation 2-1 was used to calculate LCC.

Annual maintenance to the solar-electric powered water pumping system was estimated to cost one percent of the initial cost per year. The same method was used to account for maintenance of a petroleum-electric powered water pumping system. Since this was considered to be a constant cost over time, it needed to be converted to present value. This was calculated using equation 2-2.

In meeting with the solar suppliers, it was revealed that corrosive water in a borehole would require the pump to be partially replaced every three years. This was estimated to cost one-third of the original pump price each time. Since the quality of the water at the Nyangajo borehole is unknown, this factor will be applied to both the solar electric and petroleum-electric powered water pumps.

Salvage value at the end of the 20 year life cycle was estimated to be worth 50 percent of the original value of the solar panels (URL 3).

Future estimated replacement costs and salvage value were converted to present value by using equation 2-3.

The discount rate used was seven percent (OMB Circular A-94 1992). Energy inflation was assumed to be three percent. Since there is no energy cost associated with solar-electric powered water pumping, this only applies to the petroleum generator powered option. Fuel costs were converted to present day value by using equation 2-4.

Emissions Calculations

Carbon dioxide (CO_2) emissions resulting from the use of a petroleum powered electricity generator were calculated. The following equation shows the weight of resulting CO_2 emissions released per volume of petroleum consumed by the generator (U.S. EPA 2010):

$$2{,}421\ g/gallon\ x\ 0.99\ x\ \left(\frac{44}{12}\right) x \left(\frac{gallon}{3.785L}\right) = 2311\ g/L = 2.32\ kg/L \tag{3-5}$$

Where:

2,421 g = the mass of carbon per gallon of petroleum

0.99 = 99% oxidation factor

44/12 = ratio of the molecular weight of CO_2 (one carbon atom at 12 and two oxygen atoms at 16 each, equaling 44) to the molecular weight of carbon (12)

Gallon / 3.785L = conversion from gallons to liters

This figure was then multiplied by the volume of petroleum needed to operate the electric water pump.

CHAPTER 4
RESULTS

Results of PV-Watts Analysis

A PV-Watts analysis was conducted to determine approximate solar insulation. Data was collected was for fixed tilt panels, followed by single and double axis tracking systems. Of the towns analyzed, Kisumu is the closest to Kendu Bay and is very similar in climate. Therefore, Table 4-1 shows solar radiation, AC energy and energy value data for the Kisumu region for an array at latitude as compared to one at various roof pitches. (Data for Kisii, Kakamega and Makindu can be found in Appendix B.)

Table 4-1. Data for fixed panels at various roof-pitches in Kisumu

Slope	Elevation (Degrees)	Direction	Array Type	Solar Radiation kWh/m2/day	AC Energy (kWh)	Energy value (KSH)
Latitude	0.7	North (0)	Fixed	5.67	5730	38505.60
4/12	18.4	North (0)	Fixed	5.48	5540	37228.8
5/12	22.6	North (0)	Fixed	5.37	5427	36469.44
6/12	26.6	North (0)	Fixed	5.25	5297	35595.84
7/12	30.3	North (0)	Fixed	5.12	5155	34641.60
8/12	33.7	North (0)	Fixed	4.98	5007	33647.04
9/12	36.9	North (0)	Fixed	4.84	4853	32612.16
10/12	39.8	North (0)	Fixed	4.71	4702	31597.44
11/12	42.5	North (0)	Fixed	4.56	4535	30475.20
12/12	45.0	North (0)	Fixed	4.44	4405	29601.60

The overall average solar radiation for the four towns was 5.63 kWh/m^2/day. The data points ranged from 4.79 to 6.54 kWh/m^2/day, while peaking in February and September. This is graphed in Figure 4-1.

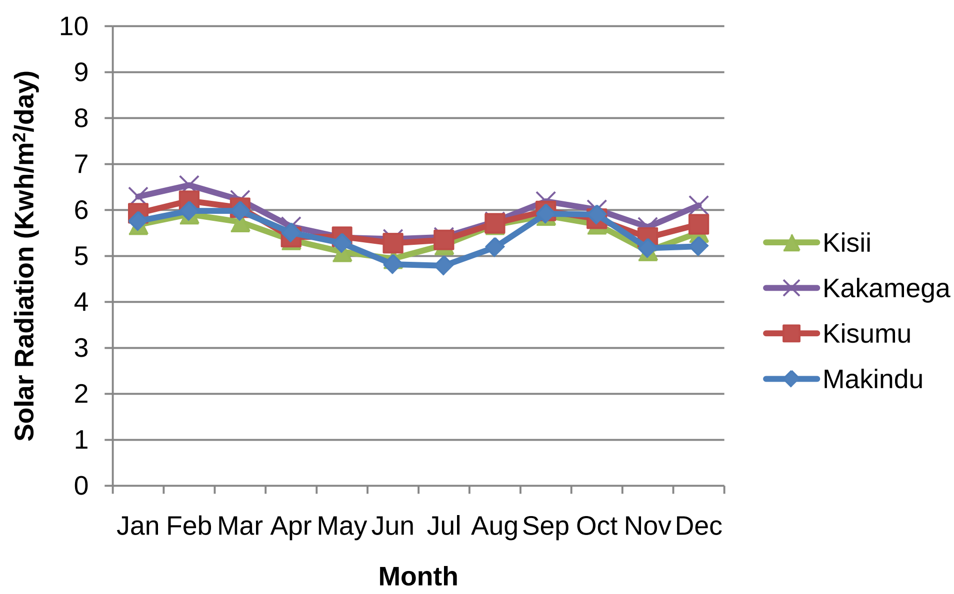


Figure 4-1. Solar radiation at latitude by month

Throughout a typical year, the available solar radiation captured using fixed access panels ranges from 4.79 to 6.54 kWh/m^2/day for the selected towns. If single-axis tracking is to be used, then the solar radiation ranges from 5.89 to 8.29 kWh/m^2/day and if double-axis tracking is used then, the solar radiation ranges from 6.31 to 8.68 kWh/m^2/day. The difference between the solar radiations captured using fixed or single-axis tracking for the town of Kisumu (the closest to Kendu Bay) ranges between 0.86 and 1.57 kWh/m^2/day, and the difference between single-and double-axis tracking ranges between 0.09 to 0.57 kWh/m^2/day. These values are shown in Figure 4-2.

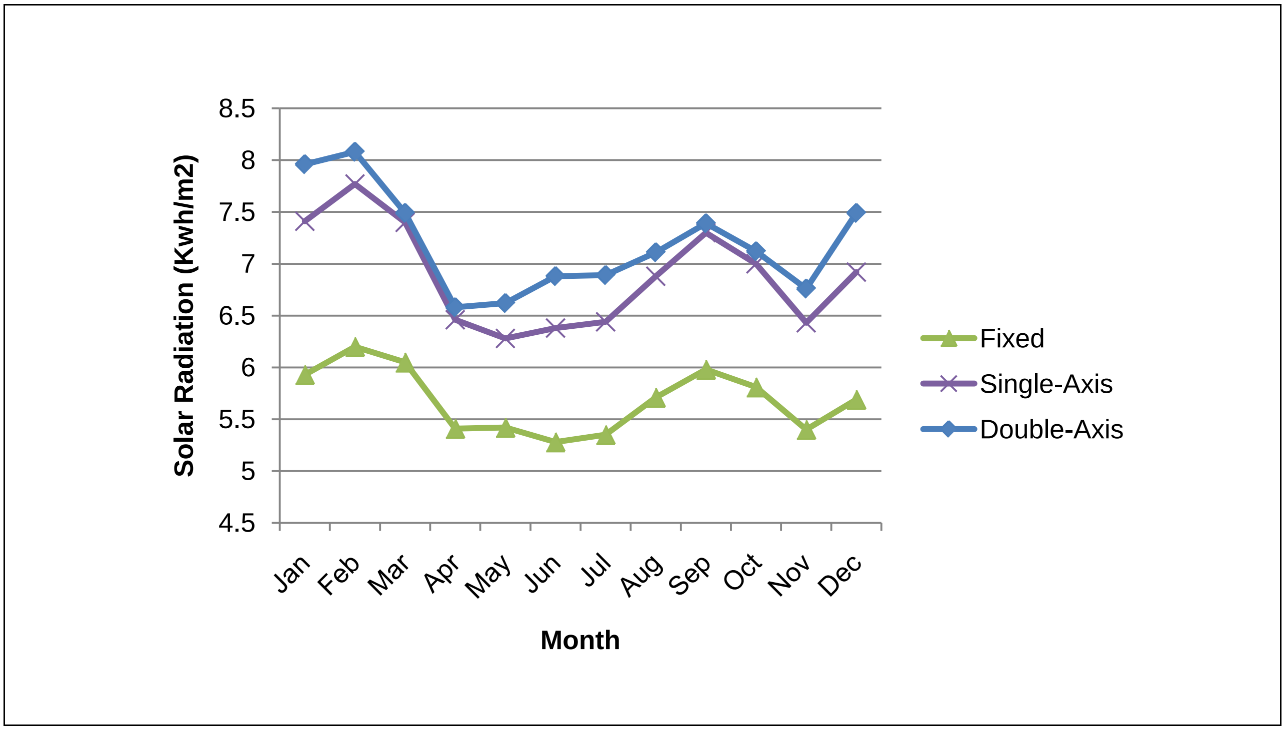


Figure 4-2. Solar radiation for Kisumu using fixed mounting, single- or double-axis tracking

Results of Calculations for Implementation

Hydraulic energy was calculated using equations 3-1 through 3-3. The total head was taken as the sum of the tank height (2.63m), vertical distance from the tank to the well (15.24m) and the static water table (23.3m). The figure of 23.3m was estimated to be the static water table for the 70m borehole. The hydraulic power requirement was calculated to be 2.22 kWh/day.

This figure was then used in equation 3-4 with the average solar irradiance value of 5.67 kWh/m^2/day (for the Kisumu region) to calculate required solar array power. The value of 0.85 was used for array mismatch factor and 0.4 was used for the daily subsystem efficiency of the pump. The solar array size needed is 1.412 kWp or 1412 Wp.

Results of Life Cycle Cost Analysis

Price quotes were gathered from two different solar-power companies. The overall expenses are compared in Table 4-2 and Figure 4-3. The prices received varied by nearly $7,000. Meeting minutes and actual price quotes and specifications from each company have been enclosed in Appendices C through F.

Table 4-2. Comparison of price quotes for solar-electric powered water pumping systems.

		COMPANY	
		Company A	Company B
COMPONENT	Pump	$ 2,250.00	$ 1,980.00
	Solar panels	$ 4,320.00	$ 9,000.00
	On/Off Control	$ 220.00	
	Accessories	$ 424.48	$ 991.00
	Well Cover	$ 292.50	$ 110.00
	Lighting arrestor		$ 105.00
	Support Structure	$ 775.00	
	Single-axis track		$ 2,450.00
	Cables / conduit	$ 718.88	$ 1,157.50
	Delivery	$ 625.00	$ 765.00
	Installation	$ 1,250.00	$ 1,250.00
	TOTAL	**$ 10,875.85**	**$ 17,808.50**

Company A quoted 10 panels at 120Wp each for a total of 1200Wp. At a price of US $4,320, the solar panels are about US $3.60/Wp. Company B quoted 12 panels at 175Wp each, totaling 2100Wp. At a price of US $9,000, these cost approximately US $4.24/Wp.

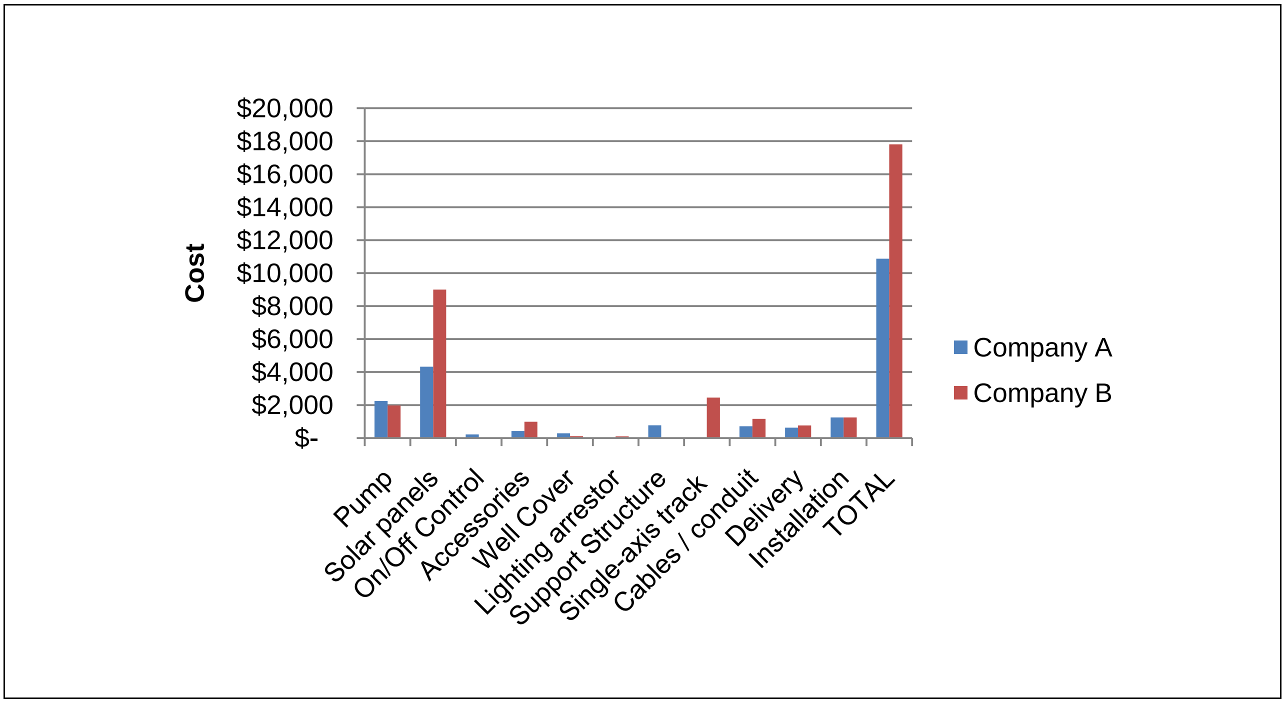


Figure 4-3. Cost comparison of components for price quotes from two companies

Using the price quote of $10,875.85 for initial costs, a life cycle cost analysis was conducted to compare the cost of solar-electric powered water pumping to that of a petroleum-electric generator powered system. An initial cost for the petroleum generator powered system was estimated by subtracting the cost of the solar panels ($4,320) and adding the cost of a typical 230 volt generator ($1,850) for a total of $8,406. These life cycle costs are shown in Table 4-3 and Figure 4-4.

Table 4-3. Twenty year life cycle costs for solar and petroleum-electric powered water pumping

	SOLAR		Petroleum Generator	
	Present Value / Year One	Present Value of Future Costs (20 Year LCC)	Present Value / Year One	Present Value of Future Costs (20 Year LCC)
Initial Cost	$ 10,876	$ 10,876	$ 8,406	$ 8,406
Fuel	$ -	$ -	$ 12,167	$ 167,068
Maintenance (Annual)	$ 109	$ 1,152	$ 84	$ 891
Pump Replacement (Partial at 3 year increments)	$ 750	$ 2,347	$ 750	$ 2,347
Salvage Value	$ 2,160	$ (558)	$ -	$ -
TOTAL		**$ 13,817**		**$ 178,712**

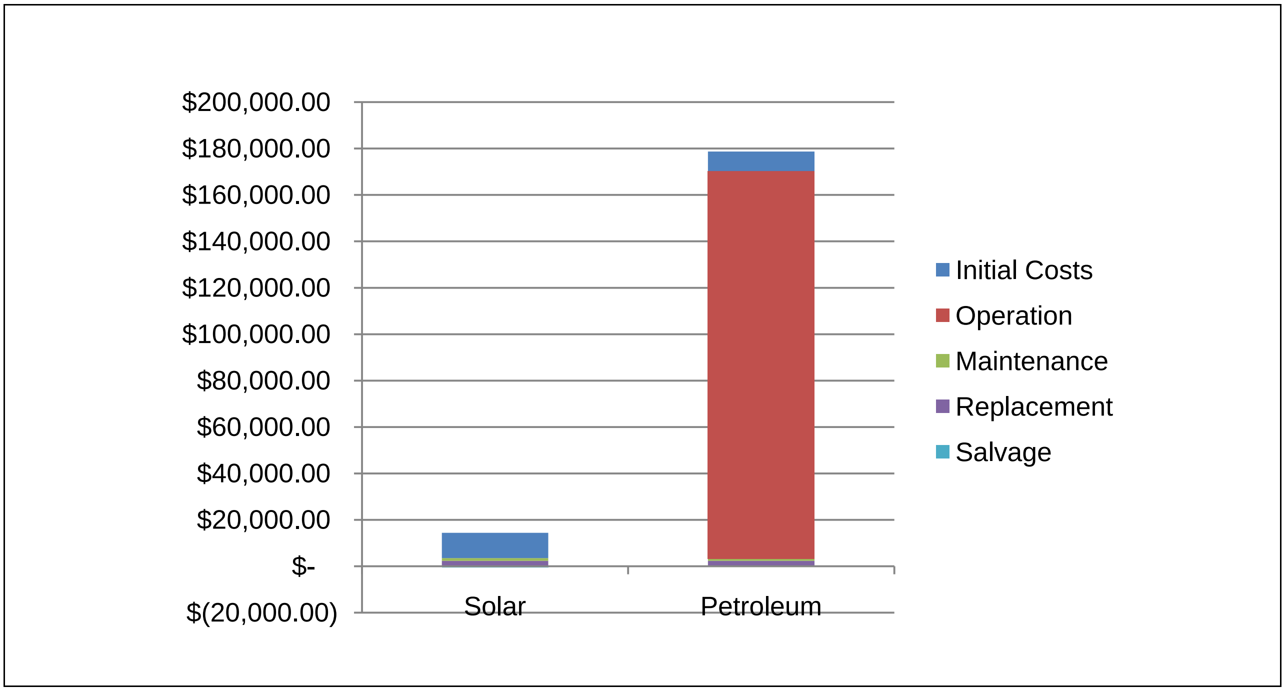


Figure 4-4. Twenty year LCC comparison

The annual cost of petroleum used to pump a daily requirement of $20m^3$ for a population of 500 is $12,167. Total cumulative life cycle costs are shown in Figure 4-5.

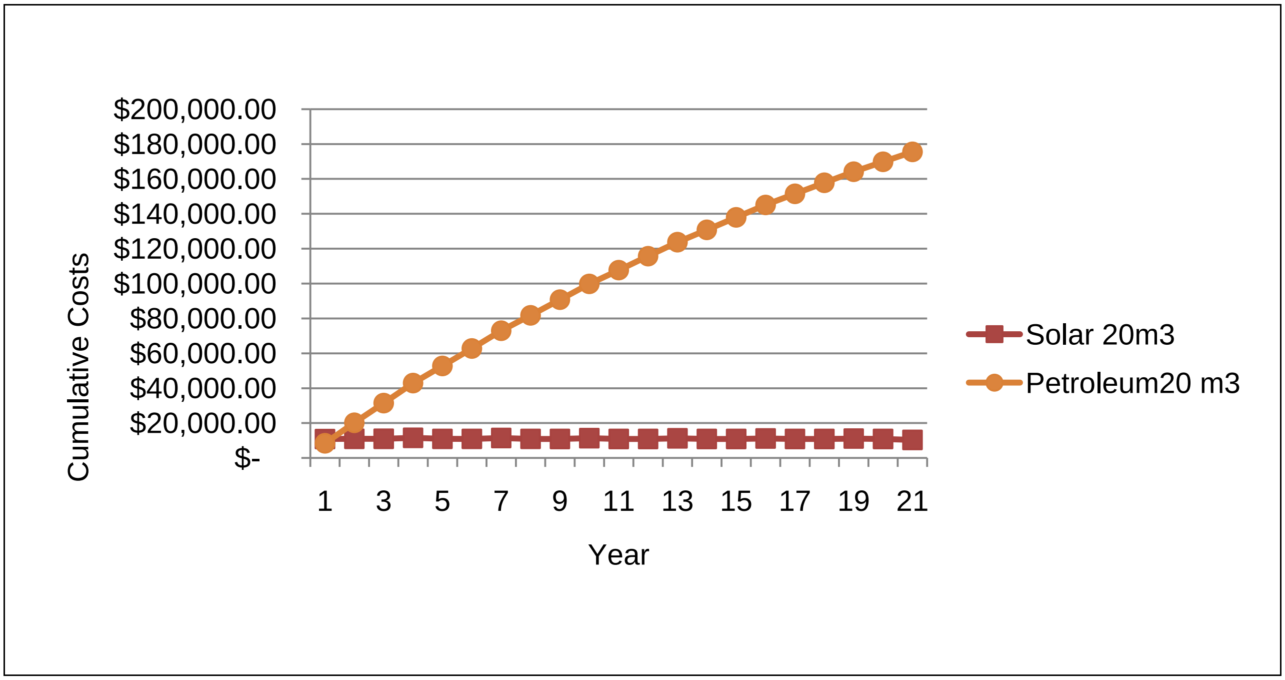


Figure 4-5. Cumulative system costs for pumping water using solar versus petroleum

Results of Emissions Calculations

The 20m^3 water demand at Nyangajo Girls Secondary School requires 27.78 liters of petroleum to pump the water tanks to their capacity. Therefore, 64.45 kg (0.064 metric tons) of carbon dioxide (CO_2) are released each time the tanks are filled. In one year 23.52 metric tons of CO_2 would be emitted from daily water pumping. Since a solar-electric powered pumping system has an estimated lifespan of 20 years, calculations have been extrapolated to show how many metric tons of CO_2 would be emitted for daily water pumping using the petroleum generator over a 20 year period. Figure 4-6 shows that daily pumping using a petroleum generator would result in the release of over 470 metric tons of CO_2. At a current population of 500, it would be necessary for the school to pump water nearly every day to comply with the World Health Organization's 20-liter minimum per person per day.

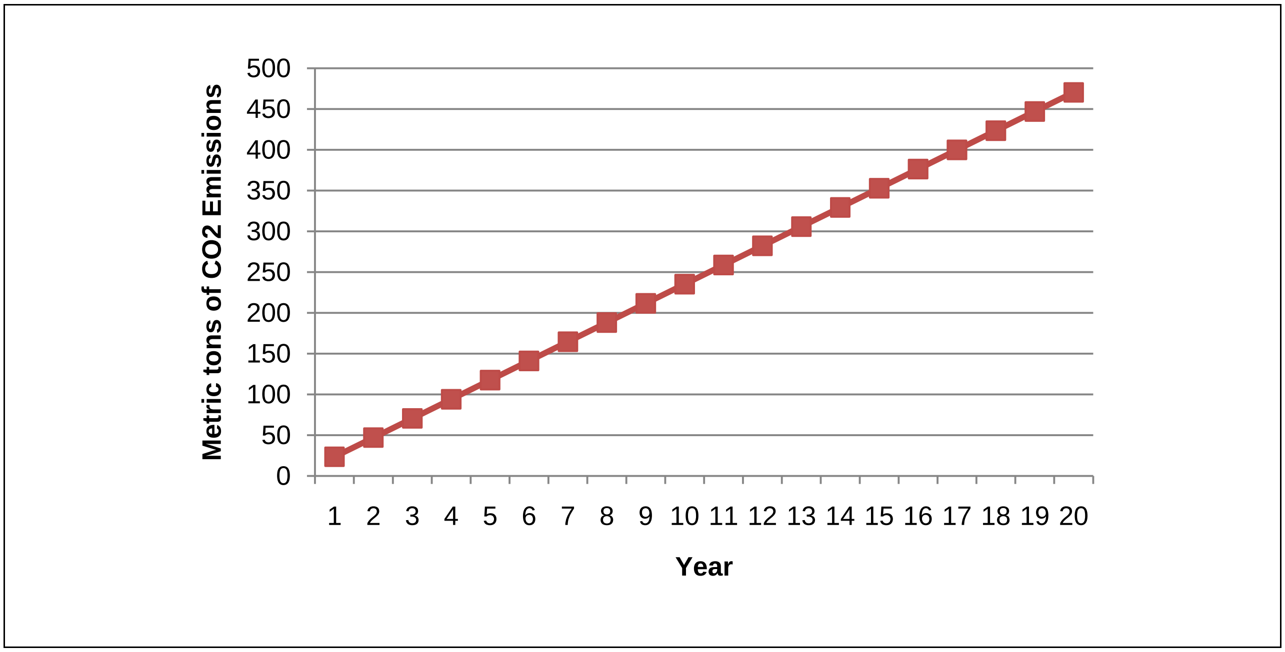


Figure 4-6. Metric tons of CO_2 emissions over 20 years of pumping water daily with a petroleum generator

CHAPTER 5
DISCUSSION

This chapter is divided into a discussion of the case studies reviewed and a discussion of the results to the research methodology. The ‘Critique of Case Studies’ provides a summary of which critical success factors were applied to each project. The ‘Critique of Research Activities’ provides a commentary of the tasks completed and explains how this example applies the critical success factor guidelines.

A Critique of Case Studies

Solar-electric powered water pumping systems have shown to be an economically feasible solution for water distribution in rural areas with sufficient solar resource, and have become more common in recent years. The size and complexity of existing systems vary. Focus on the critical success factors of technical practicality / VLOM, economic feasibility, environmental viability, socio-cultural appropriateness, adaptability and resiliency is variable among the current case studies. This is outlined in Table 5-1.

Table 5-1. Summary of system characteristics

		CRITICAL SUCCESS FACTOR						
		Technical Practicality	VLOM	Economic Feasibility	Environmental Impact	Socio-Cultural	Adaptability	Resiliency
CASE STUDY	Guatemala	***	*	**	No data	No data	***	No data
	Mvuleni	**	**	*	No data	**	No data	No data
	Wyoming	*****	*****	*****	***	No data	*****	No data
	Kyeleni	No data	No data	No data	No data	*****	No data	No data
	Kuwait	*****	No data	*****	**	No data	No data	No data
	Jordan	No data	No data	*****	*****	No data	No data	No data

The project at the Guatemalan orphanage is a good example of portability, considering the students checked the equipment with their luggage when boarding the plane. It is possible that this portability could make the panels adaptable for future uses. Conversely, since the products used were imported from the United States, maintaining and repairing the system may present some problems locally.

In the large-scale village water supply project in Mvuleni, Tanzania, most of the issues dealt with were related to funding the project. More time could have been spent focusing on the economics during the planning phase of the project, as this resulted in a delay of a year and a half. It is also possible that the village of Mvuleni will have difficulty finding repair technicians, as a lot of the equipment was imported. This installation effectively involved the community, as the residents contributed to some of the funding. The literature reviewed does not mention the adaptability or resiliency of the system.

The rural irrigation project in Wyoming focused on the environmental, technical (through the use of VLOM) and economic success factors. This project also exemplifies the critical success factor of adaptability in that some of the PV panels were installed on a trailer to use at multiple water source locations. However, there was no mention of the consideration of resiliency or socio-cultural factors, such as theft and vandalism.

The small-scale village project in Kyeleni focused on providing community-based water supply. In many solar-electric powered water pumping projects supported by ‘Water for All’, one of the main objectives is to allow children to spend more time in school, playing or participating in team sports, rather than collecting water. This project is innovative in that it achieves both by increasing the water supply when the children play on the merry-go-round. From the provided pictures, it is possible that the solar panel was located on top of the water tank to prevent theft, as well as for convenience. The literature reviewed for this case study mentions very little technical and environmental factors considered.

The study involving the computer simulation program designed for Kuwait places a strong emphasis on the technical and economic factors of implementing a solar-electric powered water pumping system. The findings help support the fact that solar-power is more environmentally sustainable, although environmental factors are not stressed upon. Also, there is no mention of socio-cultural or village-level operation and maintenance issues being considered.

Hrayshat and Al-Soud determined that using solar-power for water pumping at various locations within Jordan could result in significant differences in water yield. Taffielleh is only 30km south of Deir Alla, and the estimated water output was almost five times greater. This demonstrated the importance of collecting site data, even when locating a site within a fairly small region. This study used the ‘environmental’ criterion, in that it focused on determining the appropriateness of solar power over conventional diesel. However, it did not provide information on the technical specifications of the selected equipment, nor did it address socio-cultural issues, adaptability and resiliency of the proposed projects.

In an ideal solar-electric powered water pumping system, all of these critical success factors (Technical, VLOM, Economic, Environmental, Socio-cultural, Adaptability and Resilience) would be considered.

A Critique of Research Activities

PV-Watts Analysis

The PV-Watts analysis showed that there was no significant difference between the towns of Kisii, Kakamega, Kisumu and Makindu in terms of available solar radiation. This was compared to the analyses that were conducted in the case study on Jordanian towns. For the sites selected in Jordan, there was a wide range (between two and nine kilowatt-hours per meter squared) in available solar radiation throughout the year. Solar radiation peaked in the months from May to July, and dropped at other times. This is most likely due to the country's location between 29 and 33 degrees latitude. Additionally, towns located farther north (away from the equator) had lower levels of solar radiation, although the towns were not very far from each other. The PV-Watts analysis for the Kenyan towns showed that the proximity to the equator would result in uniform solar radiation throughout the year.

In comparing available solar radiation captured through the use of fixed, single-axis or double-axis tracking in the Kisumu region, single-axis tracking appeared to be better than fixed panels. However, there was no significant difference between that of single- and double-axis tracking. While solar panels on single-axis tracking perform better than fixed panels, there are advantages to fixed panels. These advantages include lower first costs and the ability to secure panels to a roof or other elevated structure to save space and deter theft.

Calculations for Implementation

In the calculations for hydraulic energy and solar array, data on the elevations and horizontal distances were gathered using Google Earth. Since the school was not able to provide the borehole report, the static water table was estimated to be one-third of the total borehole depth.

Life-Cycle Cost (LCC) Analysis

The two price quotes received from the Kenyan solar companies varied significantly. This is partly due to the fact that the solar panels are grouped in multiples of four, creating large intervals of variation. Company B quoted a single-axis tracking system was quoted, but this was not necessary. Removing this feature would reduce the overall quote by US $1,838, but this is still much higher than the quote received from Company A.

For the life cycle cost analysis, the initial cost of the lower price quote was used for the solar-electric powered water pumping option. Nyangajo Girls Secondary School did not provide any information on the cost of the existing petroleum-electric powered water pumping system, nor did their contractor. This cost was estimated by subtracting the cost of the solar panels and adding the cost of a typical petroleum generator. For each system, annual maintenance was estimated to be 10 percent of the first costs. Since no information was given regarding the quality of the water in the existing borehole, pump repair was estimated at a set amount every three years for both systems. As stated in Chapter 3 ‘Methodology’, fuel costs assumed a three percent energy inflation rate and a seven percent discount rate was used.

Over a period of 20, years, a solar-electric powered water pumping system will be more cost-effective than pumping 20 cubic meters of water per day using the petroleum-electric powered alternate. Due to the high cost of petroleum, a solar electric powered water pumping system breaks even in year one. This should be convincing to the school; however, initial costs could still be a deterrent. The existing system was a charitable donation, so there were no first costs. The expense of fuel combined with the unreliability of the current system has resulted in the school under-using the water supply. At the site visit in June 2010, it was evident that very little water was being consumed from the borehole. Students were collecting water with buckets from the river to use for bathing and washing clothes. In this particular case, it is likely that the actual water demand is much less than 20 cubic meters per day. This would result in a later break-even point, but this would still occur within six years. However, the World Health Organization states that at least 20L per person per day are needed for basic survival and an additional 30L per person per day are recommended assure consumption and not compromise personal hygiene (Howard and Bartram 2003).

Results of Emissions Calculations

Pumping 20 cubic meters of water every day for a year using the petroleum-electric powered water pumping system results in over 23 metric tons of carbon dioxide emissions. This is equivalent to driving a sports utility vehicle (SUV) for almost 55,000km (34,183 miles) in only one year. While the developing world produces much less carbon dioxide emissions on average, it is important for these nations to learn from the mistakes of their westernized counterparts and plan for more sustainable infrastructure projects the first time.

CHAPTER 6
CONCLUSION

In conclusion, it is recommended that Nyangajo Girls Secondary School considers installing the solar-electric powered water pumping system capable of pumping and storing $20m^3$ per day. Any water that is not used by the school can be sold to the community from the existing secondary storage tank. The six critical success factors can be achieved by the following:

Critical Success Factor 1: Technical / Village Level Operation and Maintenance (VLOM)

The pump specified is a centrifugal submerged multistage set. This is an ideal pump type, as the pump and motor are secured below the surface to protect from damage. The warranty for the pump is one year and the warranty for the solar panels is 20 years. The solar panels only require routine dusting to maintain a standard level of effectiveness. The pump is estimated to need repair only once every three years if the water is corrosive. If a qualified repair person cannot be found in Western Kenya, then one from Nairobi should be accessible every three years. A training seminar held after installation would be ideal to orient the faculty, staff and students with the new solar-electric powered water pumping system.

Critical Success Factor 2: Economic Feasibility

The presented life cycle cost analyses indicate that pumping using the solar-electric powered system quoted by Company A would break even in year one when comparing full system expenses to that of pumping the water daily using the petroleum-electric powered option. Water that is not used by the school could be sold to the community, and the school would experience greater profits with no operational energy costs. If a loan was obtained to help with the first costs of the solar-electric powered water pumping system, then selling the water would help to pay this off.

Critical Success Factor 3: Environmental Impact

Since carbon emissions have been calculated, it is known that up to 23 metric tons of carbon dioxide emissions per year will be prevented through the use of the solar-electric powered water pumping system. This is important, as Nyangajo Girls Secondary School values sustainability.

Critical Success Factor 4: Socio-Cultural Appropriateness

The two main issues in this category are theft and gender issues. Theft can be deterred through the installation of a barb-wire fence and a guard. The existing borehole already has a lockbox installed to prevent theft of the water pump.

The issue of gender is especially applicable here, as this is an all-girls school. Having a reliable water pumping system will allow the girls experience improved health benefits and to spend more time studying, as opposed to fetching water. Additionally, the installation of a solar-electric powered water pumping system would provide a real-world learning experience for these college-bound students. Students could gain knowledge in many aspects of this project, including the technical aspects of the system, the environmental factors involved and the economics of selling water to the community. This experience may inspire the girls to apply this thinking in their future careers.

Critical Success Factor 5: Adaptability

The proposed solar-electric powered water pumping system would be adaptable in that additional solar panels could be added or removed for changes in the school's enrollment. Panels that are not needed in the future for water pumping could be used for lighting the buildings. Additionally, the solar panels could be portable, as demonstrated in the Wyoming irrigation case study for use in at other locations.

Critical Success Factor 6: Resiliency

Resiliency of equipment is important when planning for infrastructure projects. The solar-electric powered water pumping system will be subject to potential natural disasters such as drought and storms. The system will be depended on through times of drought when the water level in the river decreases. Mild storms may actually help clean the dust from the solar panels, making them more effective when the storm clears. A warranty of 20 years on the solar panels indicates that the manufacturer is confident in the durability of their product.

Conclusion Summary

A solar-electric powered water pumping system would provide Nyangajo Girls Secondary School with many benefits. The school could save money that would otherwise be spent on fuel for the petroleum-electric powered water pumping system, and could also earn money by selling excess water to the community. The school will have fewer carbon emissions in choosing this alternate, and the students would have increased health benefits and be able to spend more time studying.

A project like this could be implemented in many areas of the world. Specific data would need to be gathered for the proposed site, and all six critical success factors would need to be considered. Table 6-1 provides a checklist for future solar-electric powered water pumping options, and possible sources of information are listed at the end of each section.

Table 6-1. Checklist for future solar-electric powered water pumping projects

CRITICAL SUCCESS FACTOR 1: TECHNICAL / VLOM

Water source and pump type: ___ Ground water (Submerged pump)
___ River / Lake / Pond (Surface pump)

Plan:

1. Contact solar companies in the area that could provide installation and future maintenance.
2. Provide a training session after installation.

Calculate:

$$Head(m) = Drawdown + Tank\ height + Static\ water\ table + \Delta\ elevation\ from\ tank\ to\ well$$

$$Hydraulic\ Energy\ (kWh/day) = Volume\ required\ (m^3/day)\ x\ head\ (m)\ x\ water\ density\ (kg/m^3)\ x\ gravity\ (m/s^2)$$

$$Solar\ array\ power\ required, peak\ kilowatts\ (kWp) = \frac{Hydraulic\ energy\ required(kWh/day)}{Average\ daily\ solar\ irradiation(kWh/m^2/day)\ x\ F\ x\ E}$$

Drawdown: ____ Tank Height: ____ Static water table: ____
Change in Elevation: ____ Daily Volume Required: ____ Water Density: ~ 1,000kg/m^3
Gravity: 9.81m/s^2 Average daily solar irradiation: ____ F: 0.85 E: 0.25 to 0.40

Sources: Markvart 2000, Dunn 1978, PV Watts, local solar companies, site visit

CRITICAL SUCCESS FACTOR 2: ECONOMIC FEASIBILITY

1. Contact local solar installation companies for price quotes. Supply site data and discuss calculations with the companies.
2. Calculate and compare Life Cycle Costs (LCC) for solar and other options.

Present Value Life Cycle Costs:

$$PVLCC = IC + PVM + PVR + PVF - PVS$$

Present Value Maintenance Costs:

$$P = A\left[\frac{(1+D)^n - 1}{D(1+D)^n}\right]$$

Present Value Repair and Salvage Costs:

$$P = \frac{F}{(1+D)^n}$$

Present Value Fuel Costs:

$$P = A_O\ \left[\left(\frac{1+E}{1-D}\right)\left(1 - \left(\frac{1+E}{1+D}\right)^n\right)\right]$$

Initial Cost: ____ Annual Maintenance Cost: ____ Cost & Frequency of Repair: ____
Salvage Value at End of Life: ____ Discount Rate: ____ Study Period (years): ____
Fuel Inflation (Escalation): ____ Annual Cost of Fuel: ____

Sources: ASTM E 917-89, Ruegg and Marshal 1990, OMB A-94, URL 3

CRITICAL SUCCESS FACTOR 3: ENVIRONMENTAL IMPACT

Calculate Carbon dioxide (CO_2) emissions from petroleum or diesel electricity generator.

Emissions from Petroleum

$$2{,}421\ g/gallon\ x\ 0.99\ x\ \left(\frac{44}{12}\right) x \left(\frac{gallon}{3.785L}\right) = 2311\ g/L = 2.32\ kg/L$$

Emissions from Diesel

$$2{,}778\ g/gallon\ x\ 0.99\ x\ \left(\frac{44}{12}\right) x \left(\frac{gallon}{3.785L}\right) = 2664\ g/L = 2.66\ kg/L$$

Multiply the above factor(s) by the amount of petroleum or diesel required to fuel the generator to pump the daily water demand.

Sources: U.S. EPA, site visit

CRITICAL SUCCESS FACTOR 4: SOCIO-CULTURAL APPROPRIATENESS

Plan to:

1. Involve the community in the planning of the project.
2. Determine suitable methods to deter theft (fence, guards, mounting system, etc.).

Sources: Ray 2007, local solar installation companies

CRITICAL SUCCESS FACTOR 5: ADAPTABILITY

Plan for:

1. Increase or decrease of solar panels needed for water pumping
2. Future uses for solar panels (i.e. building electrification)
3. Portability for use at other locations

Sources: local solar installation companies, site visit

CRITICAL SUCCESS FACTOR 6: RESILIENCY

Consider durability relative to site location:

1. Natural disasters (i.e. storms, drought, earthquakes, etc.)
2. Review manufacturer's warranty
3. Evaluate success of past projects in area over time

Sources: local solar installation companies, climate data

CHAPTER 7
RECOMENDATIONS FOR FURTHER RESEARCH

There are many ways this research can be expanded on. These include 1) continuing research on funding the first costs associated with water infrastructure systems, 2) improving water quality, 3) investigating alternate sources of water procurement to work in conjunction with solar-electric powered water pumping, and 4) exploring other solar applications. These are explained as follows:

Since neither of the solar companies consulted in Kenya offer financing, an effective loan system could be explored to help with the initial costs of installing a solar-electric powered water pumping system. The Government of Kenya could develop a loan system to help fund water infrastructure projects like this one.

Another important issue is water quality. An effective method of removing bacteria that cause waterborne diseases could be investigated. Additionally, an estimated 15 percent of people living in the Nyanza province have fluorosis (Neurath 2005). This is moderately low, considering 30 to 60 percent of the population in other areas of the country has fluorosis. Fluorosis is a condition caused by high levels of naturally occurring fluoride in water, which can result in mild tooth decay to severe crippling of bones. People are more susceptible to the harmful effects of this as children, when their teeth and bones are developing. An effective means of providing for the removal of both pathogens and fluoride within a solar-electric powered water pumping system could be researched.

Western Kenya is a region that has more rainfall than other parts of the country. Nyangajo Girls Secondary School has harvested rainwater in the past, and intends to implement this in the future. Re-implementing a new and improved school-wide rainwater harvesting system would enable the school to meet their water demand through cloudy periods when the solar-electric powered water pumping system is less effective. Combining these two water procurement methods may reduce the anticipated demand of the solar-electric powered system, resulting in lower first costs for fewer solar panels. Combination solar and rainwater harvesting systems could be investigated for wide-scale use throughout the region and in other parts of the world that have similar climatic conditions.

Lastly, in areas such as Nyangajo Girls Secondary School that are off of the electric grid, solar panels and inverters could be explored as a main source of electrification. While solar electricity is common in this part of Africa, it could be considered for wide-scale use by the Government of Kenya. This would result in the development of a nation that is more sustainable, producing fewer emissions than those of already developed nations.

APPENDIX A NOTES FROM NYANGAJO GIRLS SECONDARY SCHOOL

Location: St. Francis Nyangajo Girls Secondary School, Kendu Bay

Attendees: Alex Cosgrove, Kathryn Frederick, Michael Mazer, Jane Odhiambo, Tobias Omollo, Steven Schaenzer

Date: June 9th and 11th 2010

Questions

1. Q. When was the water storage tank installed? What is its capacity? Is it supplied via
   RWH?
   A. 15,000L Borehole
2. Q. Current number of students?
   A. 450
3. Q. Area of site for library?
   A. Northeast of "Form III East"
4. Q. What is the planned size of the library?
   A. 240 sq m (~ 2,590 square feet)
5. Q. Where is drinking water obtained? How is it treated?
   A. 15,000 L tank. School treats with chlorine tables.
6. Q. How is water obtained from river?
   A. Girls fetch water from the river to be used for bathing and washing clothes.
7. Q. What is the status of the borehole?
   A. It has a submerged pump, powered by a petroleum generator. School has not been satisfied with the system since installation due to the price of petroleum.
8. What are other buildings constructed of?
   A. Concrete, burnt brick, SSBs
9. Q. Most important aspect for future projects at Nyangajo School? Water is most important.
   a) Community asset
   b) Capital cost
   c) O&M
   d) Ease of installation
   e) Sustainability
   f) Operational cost/ energy
   g) Other: Recruitment

Notes

- Generator powered water pumping system was installed in May 2010.
- The water is treated with Waterguard after water comes from the tap.
- Original pump was replaced
- The pump has only been used once since the replacement generator was brought. (As of June 9, 2010)
- Contractor was hired by Vision Foundation
- The school would like to implement rainwater harvesting at new library building
- Water is most important aspect at Nyangajo

15,000L tank information:

- The 15,000 L tank pipes to kitchen and spigots at dorms.
- Once the 15,000L tank is approximately ¾ full, it will supply a 5,000L tank. This 5,000L tank is to be used for community supply. However, due to current issues with the system, the community has not been notified of this yet.
- 6cm diameter into from borehole
- 2.5cm diameter out of tank to kitchen
- <200m from borehole (To be verified upon receipt of plans)

Other tanks:

- 2 (1,000L)
- 2(500L)
- To be used with PVC pipe for rainwater harvesting
- Concrete rainwater harvesting tank (~10,000L), hasn't been used for 2-3 years due to a leak. Vision foundation may pursue this as a next project.

Generator Information:

AC	DC
230v/400v	12v
Freq 50Hz	8.3A
Rated Output 5kVA	
Max output 5.5kVA	

- Takes one day to refill 15,000L tank -8hrs
- 70m deep borehole with pump ~50m deep (to be verified upon receipt of plans)
- Fuel gasoline (petroleum)
- Nat 7000/7000E
- Generator requires 2,000Ksh/day for petroleum to pump a full 15,000L water tank
- Petroleum costs 92-100Ksh/L
- Generator ~5.3 hp (to be verified upon receipt of plans)
-

Borehole Information:

- $20m^3$/day for domestic use (60% of total yield, 10 hrs max pumping/day)
- Class of H_20 reservoir "B"
- Category of application "B"
- Max recommended depth 120m
- From tank to pump ~150-200m (to be verified upon receipt of plans)
- Pump was not compatible with the original generator.

Nearby AC Power:

- Transformer bought in December
- Stuck in Bureaucracy

School Information:

- There are four dorms, each housing over 80 students
- Newer dorms – cubical plan
- Older dorms – hallway with rooms
- Older dorms are 19m x 7m
- 1,000L Tank costs 12,000Ksh, but could find for as little as 7,000Ksh
- Dorms are congested and there is also a need new classrooms
- Tobias has been working here 5 years as the deputy principal. (Normally female administration is required at an all girls school, but this may be an exception because it is an arid area

Area Information:

- Awach Kibuo River – turbid and not potable
- There are two rainy seasons: Mar-May and Oct-Dec
- Mean annual rainfall 1,200m
- Temperature is high in January and low in July
- Climate: equatorial savannah
- Land use: settlement, farming, grazing
- Crops maize, sorghum, beans
- No soil cover and erosion in some areas

APPENDIX B: PV-WATTS ANALYSIS

Kisii

Slope	Elevation (Degrees)	Direction	Array Type	Solar Radiation kWh/m^2/day	AC Energy (kWh)	Energy value (KSH)
Latitude	0.7	North (0)	Fixed	5.48	5601	37638.72
4/12	18.4	North (0)	Fixed	5.32	5442	36570.24
5/12	22.6	North (0)	Fixed	5.22	5339	35878.08
6/12	26.6	North (0)	Fixed	5.11	5218	35064.96
7/12	30.3	North (0)	Fixed	4.98	5086	34177.92
8/12	33.7	North (0)	Fixed	4.86	4948	33250.56
9/12	36.9	North (0)	Fixed	4.73	4803	32276.16
10/12	39.8	North (0)	Fixed	4.60	4660	31315.20
11/12	42.5	North (0)	Fixed	4.47	4517	30354.24
12/12	45.0	North (0)	Fixed	4.35	4378	29420.16

Kakamega

Slope	Elevation (Degrees)	Direction	Array Type	Solar Radiation kWh/m^2/day	AC Energy (kWh)	Energy value (KSH)
Latitude	0.7	South (180)	Fixed	5.88	5949	39977.28
4/12	18.4	South (180)	Fixed	5.74	5803	38996.16
5/12	22.6	South (180)	Fixed	5.64	5701	38310.72
6/12	26.6	South (180)	Fixed	5.52	5579	37490.88
7/12	30.3	South (180)	Fixed	5.40	5446	36597.12
8/12	33.7	South (180)	Fixed	5.27	5305	35649.60
9/12	36.9	South (180)	Fixed	5.13	5157	34655.04

10/12	39.8	South (180)	Fixed	5.04	5058	33989.76
11/12	42.5	South (180)	Fixed	4.87	4865	32692.80
12/12	45.0	South (180)	Fixed	4.73	4722	31731.84

Makindu

Slope	**Elevation (Degrees)**	**Direction**	**Array Type**	**Solar Radiation kWh/m^2/day**	**AC Energy (kWh)**	**Energy value (KSH)**
Latitude	0.7	North (0)	Fixed	5.46	5509	37020.48
4/12	18.4	North (0)	Fixed	5.33	5381	36160.32
5/12	22.6	North (0)	Fixed	5.24	5290	35548.8
6/12	26.6	North (0)	Fixed	5.14	5182	34823.04
7/12	30.3	North (0)	Fixed	5.02	5063	34023.36
8/12	33.7	North (0)	Fixed	4.91	4938	33183.36
9/12	36.9	North (0)	Fixed	4.79	4808	32309.76
10/12	39.8	North (0)	Fixed	4.67	4678	31436.16
11/12	42.5	North (0)	Fixed	4.55	4547	30555.84
12/12	45.0	North (0)	Fixed	4.43	4418	29688.96

APPENDIX C: MEETING MINUTES-DAVIS & SHIRTLIFF

LOCATION: Davis & Shirtliff office, Nairobi, Kenya

ATTENDEES: Norman Chege, Mike Mugo, Alex Cosgrove, Kathryn Frederick, Mike Mazer, Steve Schaenzer

DATE: Thursday, 3 June 2010

TIME: 1:00 PM

QUESTIONS DISCUSSED

1. How is borehole recharge rate determined?
   A borehole test report is given to the owner from the installer. This information would be contained in the borehole report.

2. Can backup batteries / inverters be used to pump water at night?
   This is not recommended, as batteries require too much maintenance. Pumping should occur during the day. A larger reservoir should be used to store water for use when the pump is not in use.

3. What is the recommended material for pipes? PVC or GI?
   PVC is usually used since it is cost-effective and has low friction. There is a friction chart for pipe spans at 100m increments.

4. What is recommended for fluoride removal?
   Davis & Shirtliff does not specialize in water treatment.

5. How do you determine if there are minerals in the water that will damage the equipment?
   A hydrologist will submit a report regarding the groundwater quality.

6. What kinds of pumps are used for different situations?
   Surface pump is for rivers and the borehole pump is for boreholes.

7. What factors need to be known to implement a solar powered water pumping system?
   Vertical lift, recharge rate, required volume, distance from source, tank size

8. What is the required maintenance? What is the lifespan?

There are hardly any maintenance costs. The panels may require dusting. The lifespan of the panels and the pump is 20 years. There is a 2 year warranty on the products.

9. How do you recommend dealing with issues of theft and vandalism?
   Theft is a big issue. A solar panel could be welded to a tank to prevent theft.

10. How far can water be pumped from a river?
    Depends

11. What is the maximum cable distance?
    20m

12. Is there a low volume, high pressure portable pump that could be used for brick erosion tests?
    All pumps are available on website.

13. What are typical costs for the equipment?
    These are determined by the head height and the flow rate.
    Davis & Shirtliff has a high head borehole pump for $3,000, which requires 1,400 W. There is a low head borehole pump for $1,000, which requires 160 W.
    The total package including solar panels ranges from $8,000 – 12,000. (A solar panel costs ~ $5,000.)
    For much smaller applications, there is a surface pump costing approximately $20. It has a flow rate of 1.8 GPM and requires 80W.

14. What is a typical daily demand for a solar-electric powered water pumping installation?
    20m^3/day, 80 – 100 m deep

15. What is done to prevent flocculation of water?
    Flocculation will not damage the pump.

NOTES:

Tables and specifications are available on the Davis & Shirtliff website.

The Grundflos software for capturing the requirements is available on the website.

Chlorine water treatment at the tank is most cost-effective method.

APPENDIX D: MEETING MINUTES – CENTER FOR ALTERNATIVE TECHNOLOGIES

LOCATION: Center for Alternative Technologies office, Nairobi, Kenya

ATTENDEES: Nawir Ibrahim, Leonard Mwangi, Kathryn Frederick, Steve Schaenzer

DATE: Wednesday, 14 July 2010

TIME: 9:30 AM

ITEMS DISCUSSED

1. PV and petroleum power sources can be used interchangeably for water pumping, but only if a transformer is used. A transformer may cost approximately $1,500.
2. On the quote provided for Nyangajo Girls Secondary School, the only item that applies specifically to the pump is Item 1.00 “Lorentz Submersible Solar Pump PS1800 C-SJ1-25+ C.
3. Single axis tracking can result in 25-30% more water being pumped, than in that of fixed panels. If Nyangajo Girls Secondary School has a population of 500, and requires 20L per person per day, then the daily requirement of 10,000L can be achieved per the Lorentz Compass simulation software. The single axis tracker allows pumping to begin earlier and run later.
4. A fixed frame structural mounting system costs 25% of that of a single –mount system. Per the Lorentz Compass simulation software, a fixed structural frame should meet the demands of Nyangajo Girls Secondary School.
5. Maintenance of the solar panels requires dusting with a damp cloth. Dusty panels may result in an inefficiency of 20-30%. Panels that are oriented at zero degrees require more cleaning than those that are oriented at a slight angle.
6. Panels specified can be reduced or increased by multiples of four.
7. Water can be corrosive on pumps, and dirty water can wear the pump out. A pump report should be obtained from the school to determine water quality and properties that may affect the pump.
8. The pump listed consists of three parts: 1) drive, 2) pump and 3) controller. Each is approximately one-third of the overall line item cost. If there is a lot of wear and tear on a pump, it may have to be replaced after two years. This would require replacing only one-third of the overall pump.
9. There is a two-year warranty on pumps. In that time, parts will be replaced for free, but the client will have to pay for labor and shipping.

10. It would be ideal to obtain lightning frequency data for the region.
11. Pump efficiency is a factor in calculating the power. The pump specified (PS 1800 C-SJ1-25) has an efficiency of 40%.
12. Power in watts is calculated as follows:

$$\text{Watts} = \frac{\text{Vertical feet x GPM x 18.8}}{\text{Pump Efficiency}}$$

Or

$$\text{Watts} = \frac{\text{Vertical meters x LPM x 16}}{\text{Pump Efficiency}}$$

13. Total head = tank height + well to basin + static level + drawdown
14. If the correct size pipe is used, pipe length is not a factor. Pipe sizes can be selected from chart provided by Center for Alternative Technologies.
15. For lowering the pump into the outlet, a 40mm (1.25") pipe was quoted.
16. The PS1800 pump can work with four, eight or twelve modules. The PS4000 can add many more.
17. The Center for Alternative Technologies has provided the 2010 IRES team access to the Lorentz Compass Simulation Software as well as a brochure comparing solar and diesel-electric powered water pumping systems.
18. Panels higher off of the ground allow for more security but are harder to clean.
19. Specified pump (PS1800 C-SJ1-25+ C) with 8 panels and no tracker yields approximately 11.8m^3/day
20. Specified pump (PS1800 C-SJ1-25+ C) with 12 panels and tracker yields approximately 23m^3/day.

APPENDIX E: PRICE QUOTE AND SPECIFICATIONS – DAVIS & SHIRTLIFF

D&S DAVIS & SHIRTLIFF

know H_2Ow through experience

Borehole and Surface Pumps
Swimming Pool Equipment
Water Treatment
Solar Power Products

SYSTEM CERTIFICATION ISO 9001:2000 SGS

DAVIS & SHIRTLIFF LTD • PO Box 41762 - 00100, Nairobi, KENYA • Tel: (+254 20) 6968000, 558335 • Fax: (+254 20) 557617 • d&s@dayliff.com

Ref: NC/Q/2164
Date: 6th July 2010

Kathryn Frederick
E-mail: frederickkathryn@yahoo.com

Dear Kathryn,

QUOTATION FOR SUPPLY OF A SOLAR POWERED SUBMERSIBLE PUMP

We refer to your enquiry regarding the above, and now have the pleasure of forwarding to your attention this quotation, terms and conditions as detailed hereunder: -

1. **Borehole Conditions**

Depth approximated at maximum	-	70m
Water rest level	-	N/a
Test pump output	-	N/a
Test pump water level	-	N/a

Site Conditions

Water Requirement per day	-	**15.0m^3/day**
Elevation to tank	-	15.24m
Height of tank	-	2.63m
Distance from borehole to tank	-	70m
Friction pipe Losses using PVC pipes	-	5m
Total head	**-**	**92.87m**

2. **Requirement**

To offer a quotation for a borehole solar submersible pumps, assuming maximum head of 93m.

Equipment Specifications

a) **Grundfos SQFlex Model 2.5-2** helical rotor pump (3") complete with MSF 3 motor (3") and 2m cable with water level electrode. This pump is rated at a maximum of **2.4m^3/hr** at the head. The rated flow per day is approximately **16.0m^3/day** assuming a 7hours of sunshine/day with a solar power requirement of 1200Watts
b) **Grundfos CU200** Power Controller for system control including monitoring and alarm functions, and offering the facility for high level control floatswitch connection. The unit provides indication of pump operation, input power and dry running stoppage.
c) **10No. Dayliff 120Watts;** 12 VDC crystalline PV solar modules. The panels are to be series connected.
d) Accessories include necessary riser piping, module support structure, 6mm2 DC electric cabling and submersible drop cabling, and submersible cable joint.

3. **Equipment Price Details**

Qty	Description	Unit Price	Disc	Net Total
	SQFlex Main Components			
1	Grundfos SQF 2.5-2 Pump c/w motor	225,000	20%	180,000
10	Dayliff 120Watts Solar panels, 12VDC	43,200	20%	345,600
1	Grundfos IO100 on/off Control Unit	22,000	20%	17,600
	SQFlex Accessories			
50	$6mm^2$ Twin flat Cable w/earth (panel inter-wiring, wind generator & f/sw)	240	15%	10,200
80	$6mm^2$ Submersible Drop Cable (connecting pump to CU 200)	750	30%	42,000
10	$6mm^2$ Underground cable	590	10%	5,310
23	1 1/4" Dayliff delivery pipes, 3m length	1,600	15%	31,280
1	1 1/4" Dayliff Starter pipe	550	15%	468
1	1 1/4" Seamless Adapter	2,600	15%	2,210
1	Submersible cable splicing Joint	3,700	35%	2,405
1	Borehole Cover c/w Sundries	36,000	35%	23,400
1	Solar Panels Support Structure-alluminium	77,500	20%	62,000
1	Transport of materials and Technicians to site	50,000	0%	50,000
1	Installation Labour	100,000	0%	100,000
	Sub-Total (KShs)			**872,473**
	Add 16% VAT			**-**
	Total Cost (KShs)			**872,473**
	or Total Cost (US$)			**10,906**

Notes:

- No connections should be made to auxiliary solar applications such as lighting, etc.
- All solar modules and the solar pump are zero-rated for VAT in Kenya. **Complete supply and installation** of borehole solar pump is exempted from VAT in Kenya.
- The setup is normally a direct connection, and therefore no battery bank is required. Pumping takes place when the sun is shining, and the water is stored in a reservoir for use during other periods.
- Quotation does **NOT** include **the plumbing accessories** from the borehole **to the reservoir tank**, which we have assumed will be provided by others. It provides for delivery pipe **only** up to the borehole surface.
- The above costs are inclusive of the installation labour charges, and and transportation of the equipment to site. Kindly note that if these services are not required, then you are at liberty to delete the same from our offer and reduce the quotation value accordingly.
- The quotation has been prepared in the absence of a drillers report, and based only on information provided on email. Should the parameters on site be different, then the quotation will be revised accordingly to suit the site conditions.

4. **Delivery**

The equipment is available ex-stock, though offered subject to being unsold at date of order.

5. **Warranty**
   20years on the solar modules, and 1-year warranty on the pump

6. **Validity**
   Due to input cost uncertainties, this quotation will be subject to confirmation at date of order.

7. **Terms of payment**
   100% upfront before supply and installation

We look forward to your further instructions in due course.

Yours faithfully,
For DAVIS & SHIRTLIFF LTD.

Norman Chege
Encl

MADE IN CHINA

DATA SHEET

Photo Voltaic Solar Modules

The heart of all effective photovoltaic solar systems is an efficient and reliable solar module, Davis & Shirtliff's policy being to source PV modules from international manufacturers who comply with the highest levels of quality, efficiency and durability standards. Options are as follows:-

CRYSTALLINE MODULES

DAYLIFF crystalline modules are sourced from Yingli and SolarWorld, both large scale manufacturers with modern factories that fully meet international standards. All modules offer the following features:-

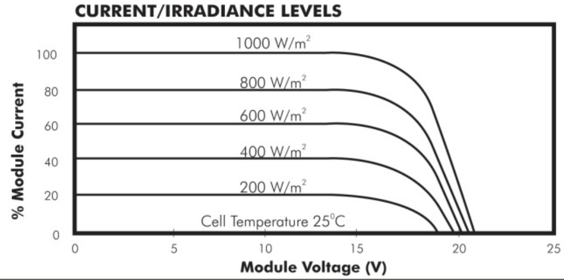
- High efficiency crystalline solar cells with minimum 15% energy conversion rates to provide maximum power even under weak light. .
- High transmission rate tempered glass with an anti-reflection coating to increase the power output and provide mechanical strength.
- Multi function water proof junction box for easy connection.
- 25 year power output warranty
- Global Certifications. UL IEC TÜV ISO 9001

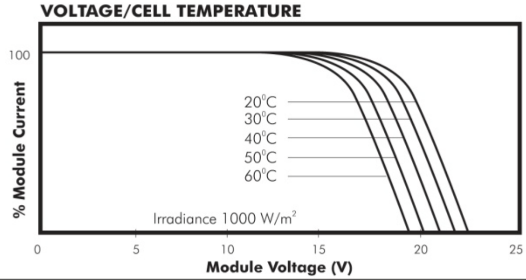
AMORPHOUS MODULES

DAYLIFF amorphous modules are sourced from Topray, a world leading manufacturer of this panel type and are of high strength design for water, shock and corrosion resistance. They feature advanced thin film technology for wider spectrum light absorption that enhances performance in low light conditions and reduces power loss at high temperatures. All panels incorporate a diode to prevent night battery discharge and 14W modules include a 2m cable and clips for direct battery connection.

DAYLIFF modules are manufactured in ISO 9001 factories and are certified to comply with international standards as well as being guaranteed to provide reliable performance over long life spans. They are quality products in terms of both technology and performance and are ideal power sources for all types of solar applications.

TYPICAL PERFORMANCE CHARACTERISTICS (Nominal 12V Cells)





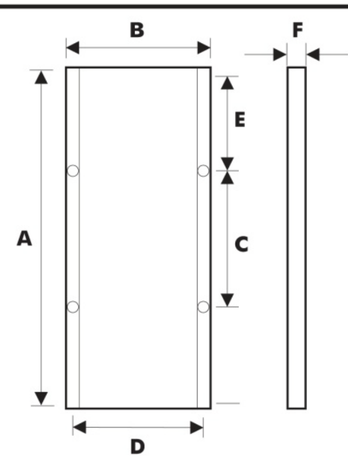
ELECTRICAL DATA

Model	Type	Rated Power (W)	Nominal Voltage (V)	Peak Voltage (V)	Open Circuit Voltage (V)	Short Circuit Current (A)	Number of Cells
TR14	Amorphus	14	12	17.5	23	1.22	-
TR32	Amorphus	32	12	17	21.5	2.14	-
YL15	Multicrystalline	15	12	17.5	21	1	36
YL20	Multicrystalline	20	12	17.5	21	1.3	36
YL30	Multicrystalline	30	12	17.5	21	2	36
YL40	Multicrystalline	40	12	17.9	21.5	2.41	36
SW40	Multicrystalline	40	12	17.5	21	2.6	36
YL50	Multicrystalline	50	12	17.5	22	3.1	36
SW60	Multicrystalline	60	12	17.9	21.5	3.62	36
YL65	Multicrystalline	65	12	17.5	22	4.1	36
YL80	Multicrystalline	80	12	17.5	22	5.1	36
SW80	Monocrystalline	80	12	17.5	21.9	5	36
YL120	Multicrystalline	120	12	17.5	22	7.6	36
SW120	Multicrystalline	120	12	17.9	21.5	7.23	36
YL150	Multicrystalline	150	24	35	44	4.7	36

Data is given at Standard Test Conditions: Irradiance 1000W/m², spectrum AM 1.5 and 25°C cell temperature

PHYSICAL DATA

Model	Dimensions						Weight (kg)
	A	B	C	D	E	F	
TR14	922	312	-	288	-	21	4.9
TR32	1252	641	-	603	-	36	14.8
YL15	400	350	200	315	100	25	1.9
YL20	610	291	309	256	149	25	2.3
YL30	540	510	297	475	122	25	4.1
YL40	660	540	279	625	130	25	5.6
SW40	572	680	200	640	86	34	4.8
YL50	800	541	400	506	200	35	5.6
SW60	806	680	400	640	109	34	6.2
YL65	770	660	389	626	190	35	7.7
YL80	1171	540	592	507	290	35	7.7
SW80	1200	527	1172	483	643	56	7.6
YL120	1469	681	869	647	306	35	11.7
SW120	1508	680	880	640	109	34	11.8
YL150	1310	990	680	944	315	50	15.7



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NB. Contents herein are not warranted. The right is reserved to amend specifications without notice.

DS118B-02/09

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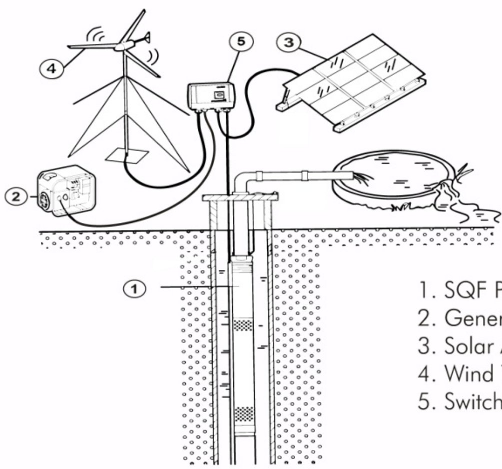
DATA SHEET

Renewable Energy Water System

SQFlex



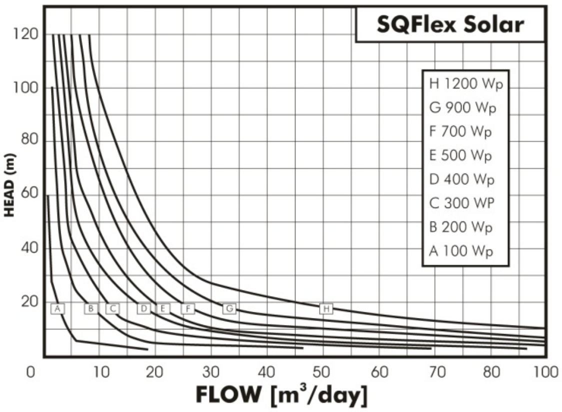
1. SQF Pump
2. Generator
3. Solar Array
4. Wind Turbine
5. Switch Unit

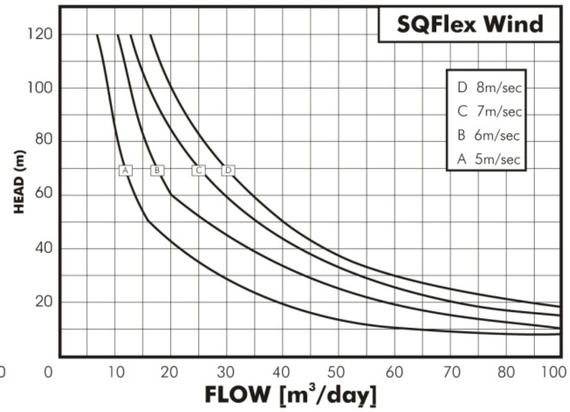
The Grundfos SQFlex pumping system is a revolutionary concept in water supply designed to work using the two most basic sources of renewable energy available - the sun and the wind. Its unique feature is the flexibility to be powered by photovoltaic solar modules, a wind driven generator or a combination of both, and the motors are also designed for battery supply and ac generator power for standby operation, the power source being selected by simple switching. At the heart of all SQFlex systems is the electronically controlled motor, which uses a sophisticated integral control module to accommodate variable voltage and frequency power inputs and also protects against abnormal operating conditions.

Another special feature is the alternative of submersible borehole type helical rotor or centrifugal pump ends to ensure maximum system efficiency throughout the performance range. With the option of seven different pump specifications the easy-to-use SQFlex computerised sizing system ensures selection of optimally efficient pump/power source combinations for all specified duty conditions. Solar systems are powered by a selectable number of four module arrays of the unique Grundfos GF43 photovoltaic modules and pump performance is dependant on the number of arrays installed.

With the ever-increasing requirement for economic and sustainable water supplies in remote areas renewable energy pumping systems are becoming the only logical solution. The combination of flexibility, performance, minimal operating costs, simplicity of installation and now acceptable investment cost that the SQFlex system offers is a major technological breakthrough making reliable and consistent water supply in remote areas a practical and economic reality.

PERFORMANCE CURVES





EQUIPMENT SPECIFICATION

Pump

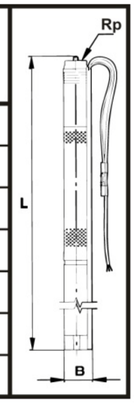
A range of three models of helical rotor pumps for high heads and low flows (suitable for 3" boreholes) and four models of centrifugal pumps for low heads and high flows (suitable for 4" boreholes) are offered with stainless steel used extensively in construction for both pump designs.

Motor

One size of the unique 900W Grundfos MSF 3 high efficiency permanent magnet motor is specified with all pump types. The motor can be powered by either DC or AC voltage within the range of 30-300V DC and 1X90-240V, 50/60Hz AC. An integral control module protects against over and under voltage (except lightening), electrical overload and over temperature and effective dry running protection is provided by a sensor in the motor cable.

Pump Data

Pump Model	Dimensions (mm)			Weight (kgs)
	L	B	Rp	
SQF 0.6-2	1185	74	1¼"	9
SQF 1.2-2	1225	74	1¼"	10
SQF 2.5-2	1247	74	1¼"	10
SQF 5A-3	815	101	1½"	10
SQF 5A-6	875	101	1½"	10
SQF 8A-3	920	101	2"	11
SQF 14A-3	975	101	2"	12



Control Units

A variety of switch boxes are available for the various installation options including IO100 for a manual solar system, IO101 for solar/generator systems and IO102 for a wind system. In addition a CU200 control unit is offered which provides for high-level switch control together with system monitoring and alarm indication.

Solar Modules

The Grundfos GF43 (43wp, 141V) amorphous silicon thin film photovoltaic solar modules are specially designed for optimal efficiency operation with SQ Flex systems though other proprietary modules can be used providing input voltage is in excess of 40V. Arrays are specified in sets of four parallel connected modules each providing 170wp power output, the number of arrays depending upon the duty requirement. Individual modules are dimensioned 1220mmx705mmx51mm and weigh 15kgs.

Wind Generator

Whisper H80 permanent magnet 120V AC type alternator powered by an advanced 3.1m diameter rotor blade ($8m^2$ swept area) to provide greater output at lower wind speeds. The unit develops peak power of 1,000W at 11m/sec (40km/hr) wind speed and will startup at 3m/sec (11km/hr) wind speed, total generation power being 6.3kWhr per day.

Accessories

A complete range of accessories including connecting cabling and fittings, drop cable, module support structures and wind generator towers are available to provide all necessary components for a complete site installation.

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APPENDIX F: PRICE QUOTE AND SPECIFICATIONS – CENTER FOR ALTERNATIVE TECHNOLOGIES

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Nairobi, Kenya

Phone: 254-2-8562034, 8561253
Fax: 254-2-8562310

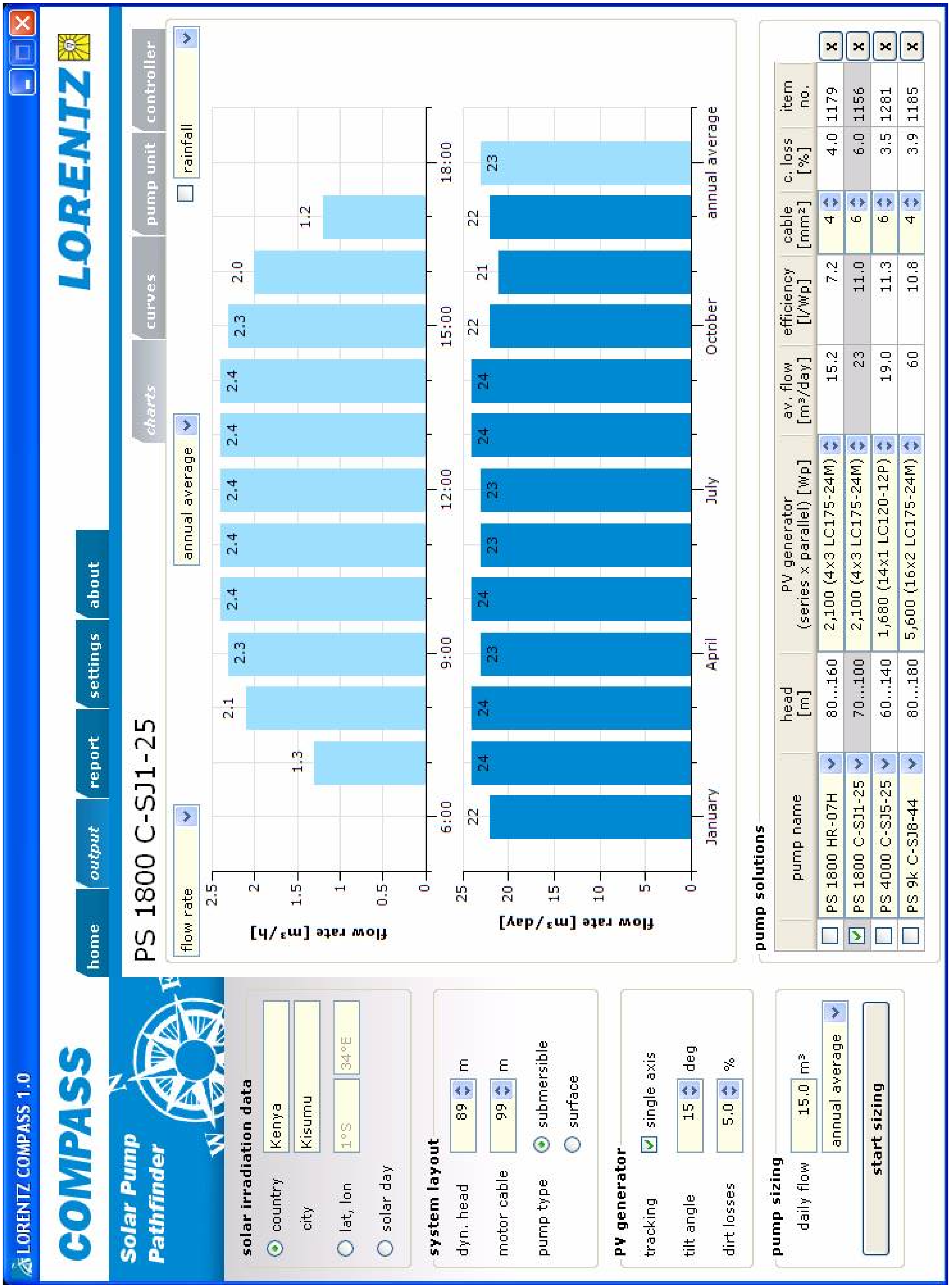
Email: info@cat.co.ke

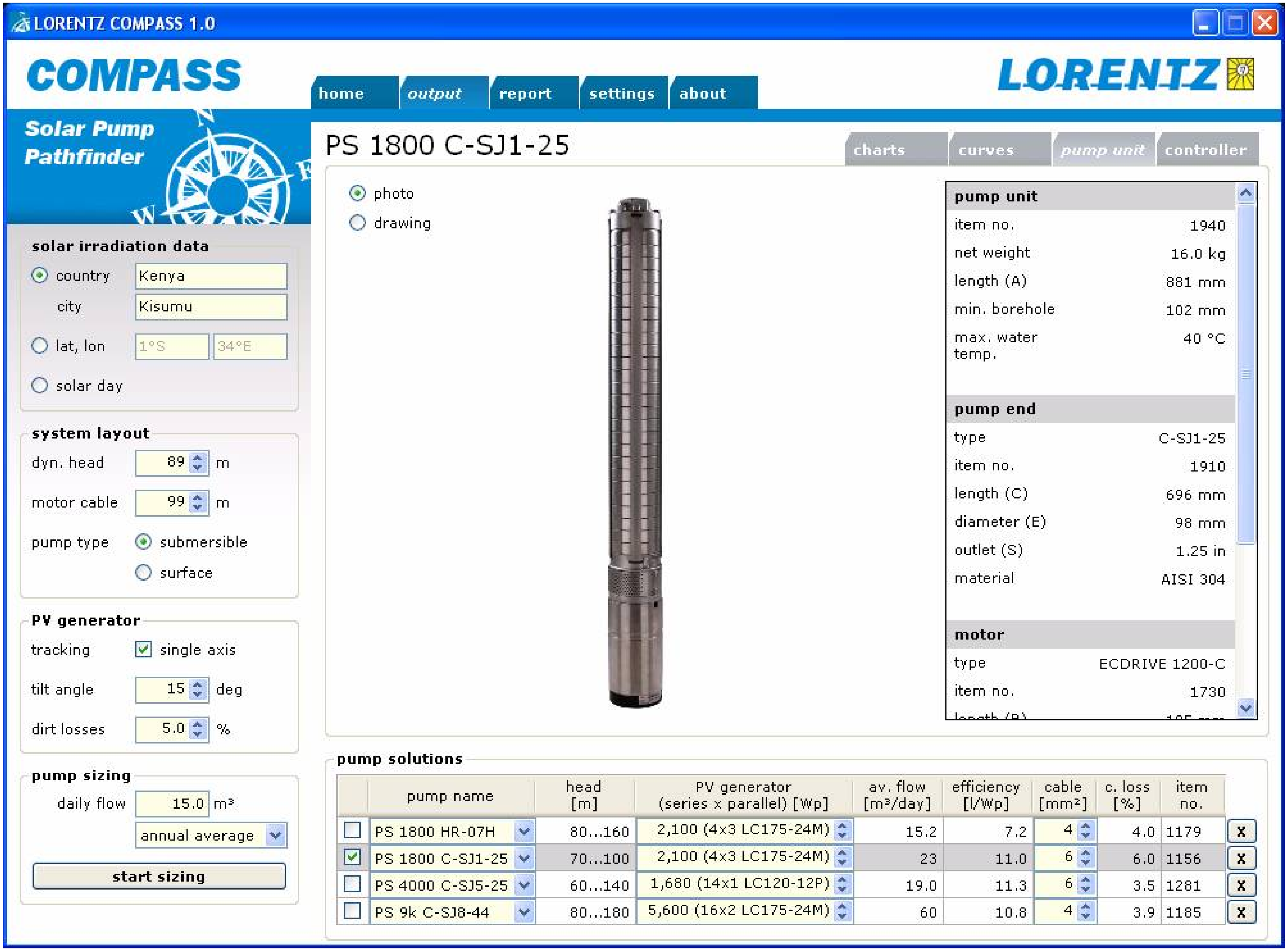
CENTER OF ALTERNATIVE TECHNOLOGIES

Quote

QUOTE TO
KATHRYN FREDERICK

NO			**Date**	**TERMS**	**VAT REG NO**	**PIN NO:**
7-0006			8th July 2010	Due on receipt	0158206R	P051184963F
ITEM	**DESCRIPTION**	**QTY**	**RATE US$**	**VAT %**	**VAT AMT**	**AMOUNT US$**
1.00	Lorentz Submersible Solar Pump PS1800 C-SJ1-25+ C	1.00	1,980.00	0%	-	1,980.00
2.00	Lorentz Splicing Kit	1.00	32.00	0%	-	32.00
3.00	Lorentz 20A PV Disconnect	1.00	250.00	0%	-	250.00
4.00	Lorentz Water Level Probe	1.00	70.00	0%	-	70.00
5.00	Lorentz 175W 24V Monocrystalline PV Solar Modules	12.00	750.00	0%	-	9,000.00
6.00	HDPE 40mm 16Bar Pipe	70.00	2.70	0%	-	189.00
7.00	Fusion of HDPE pipe to Pump	1.00	450.00	0%	-	450.00
8.00	6" Well Cover/ Adaptor/ Cable Ties/Insulating Tapes	1.00	110.00	0%	-	110.00
9.00	Delta Lightening Arrestor	1.00	105.00	0%	-	105.00
10.00	Ground Rod & Cable	1.00	92.00	0%	-	92.00
11.00	6mm 3Core Submersible Cable	80.00	6.90	0%	-	552.00
12.00	1mm 2Core Electrode Cable	80.00	1.00	0%	-	80.00
13.00	Safety Rope	80.00	1.20	0%	-	96.00
14.00	Lorentz Single Axis Tracking System for PV Modules	1.00	2,450.00	0%	-	2,450.00
15.00	10mm DC Cable Red & Black)	100.00	3.10	0%	-	310.00
16.00	Flex Conduit	50.00	0.55	0%	-	27.50
17.00	Delivery	900.00	0.85	0%	-	765.00
18.00	Installation	1.00	1,250.00	0%	-	1,250.00
VAT SUMMARY				Subtotal		17,808.50
-	@ 16.0%			VAT		-
				Total		**17,808.50**


LORENTZ COMPASS 1.0
COMPASS
Solar Pump Pathfinder
LORENTZ
home
output
report
settings
about
PS 1800 C-SJ1-25
flow rate
annual average
charts
curves
pump unit
controller
rainfall
solar irradiation data
country
Kenya
city
Kisumu
lat, lon
1°S
34°E
solar day
system layout
dyn. head 89 m
motor cable 99 m
pump type
submersible
surface
PV generator
tracking
single axis
tilt angle 15 deg
dirt losses 5.0 %
pump sizing
daily flow 15.0 m³
annual average
start sizing
flow rate [m³/h]
6:00
9:00
12:00
15:00
18:00
flow rate [m³/day]
January
April
July
October
annual average
pump solutions
pump name
head [m]
PV generator (series x parallel) [Wp]
av. flow [m³/day]
efficiency [l/Wp]
cable [mm²]
c. loss [%]
item no.
PS 1800 HR-07H 80...160 2,100 (4x3 LC175-24M) 15.2 7.2 4 4.0 1179
PS 1800 C-SJ1-25 70...100 2,100 (4x3 LC175-24M) 23 11.0 6 6.0 1156
PS 4000 C-SJ5-25 60...140 1,680 (14x1 LC120-12P) 19.0 11.3 6 3.5 1281
PS 9k C-SJ8-44 80...180 5,600 (16x2 LC175-24M) 60 10.8 4 3.9 1185


LORENTZ COMPASS 1.0
COMPASS
Solar Pump Pathfinder
home
output
report
settings
about
LORENTZ
PS 1800 C-SJ1-25
charts
curves
pump unit
controller
photo
drawing
solar irradiation data
country Kenya
city Kisumu
lat, lon 1°S 34°E
solar day
system layout
dyn. head 89 m
motor cable 99 m
pump type submersible
surface
PV generator
tracking single axis
tilt angle 15 deg
dirt losses 5.0 %
pump sizing
daily flow 15.0 m³
annual average
start sizing
pump unit
item no. 1940
net weight 16.0 kg
length (A) 881 mm
min. borehole 102 mm
max. water temp. 40 °C
pump end
type C-SJ1-25
item no. 1910
length (C) 696 mm
diameter (E) 98 mm
outlet (S) 1.25 in
material AISI 304
motor
type ECDRIVE 1200-C
item no. 1730
pump solutions
pump name | head [m] | PV generator (series x parallel) [Wp] | av. flow [m³/day] | efficiency [l/Wp] | cable [mm²] | c. loss [%] | item no.
PS 1800 HR-07H | 80...160 | 2,100 (4x3 LC175-24M) | 15.2 | 7.2 | 4 | 4.0 | 1179
PS 1800 C-SJ1-25 | 70...100 | 2,100 (4x3 LC175-24M) | 23 | 11.0 | 6 | 6.0 | 1156
PS 4000 C-SJ5-25 | 60...140 | 1,680 (14x1 LC120-12P) | 19.0 | 11.3 | 6 | 3.5 | 1281
PS 9k C-SJ8-44 | 80...180 | 5,600 (16x2 LC175-24M) | 60 | 10.8 | 4 | 3.9 | 1185

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BIOGRAPHICAL SKETCH

Kathryn Frederick earned a Bachelor of Design in Interior Design at the University of Florida where she graduated *cum laude* in 2005. She has worked in architecture and interior design firms in Atlanta and Florida. In 2006, Kathryn became a LEED AP (Leadership for Energy and Environmental Design Accredited Professional), and in 2007 passed the NCIDQ (National Council for Interior Design Qualification) exams to become a Licensed Interior Designer by the Florida Board of Architecture and Interior Design in 2008. In collaborating with many professionals of the design and construction industry, Kathryn realized that she wanted to return to the University of Florida to work on a Master of Science in Building Construction with a focus in Sustainable Construction.

Kathryn's interest in sustainability combined with her interest in foreign cultures led to her research on sustainable development in Africa. Kathryn will graduate in December 2010. Afterwards, she intends to gain powerful experience working in the construction industry and to continue to further her education.