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## 2.500 Desalination and Water Purification

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# Purification of Water in Phaeton and Paulette

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2.500 Term Project Report

May, 2009

## **Abstract**

The term project is aimed at finding a solution to the water problem in the impoverished villages of Phaeton and Paulette in Haiti. Several options for water desalination and various sources of energy for the processes have been evaluated in this paper. Based on this a sustainable solution for the problem has been proposed. Also, a scheme for optimal water usage has been recommended.

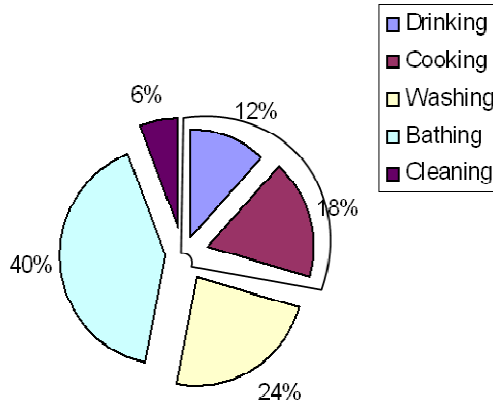
### **1) The Problem**

The villagers of Paulette and Phaeton are facing many health problems because the salinity in their well water is too high. They are forced to consume this saline water because of high cost of the pumped water supply (which is much less saline) to their village. The cost of pumped water is 1 gourde per bucket. Each family (of an average size of 5 people) is known to consume 4-5 buckets a day. The total cost of water culminates to 10% of their income. This translates into 1.27 US\$/m<sup>3</sup> of water, which is a very high cost. Many desalination plants around the world produce water at much cheaper rates than that. For example, an RO plant currently in operation at Ashkelon (Israel), produces water at 0.52US\$/m<sup>3</sup> (Sauvet-Goichon, 2007). However, given that the capacity of water production required in Paulette or Phaeton is much smaller than standard desalination plants, the cost is also bound to be much higher because the economies of scale will work against these smaller plants.

The first step to designing these plants will be to decide on the capacity. Based on data available to us, we propose a scheme to optimize water usage so that we can design the desalination unit for a smaller capacity and lower investment and operational costs. The following section details the same.

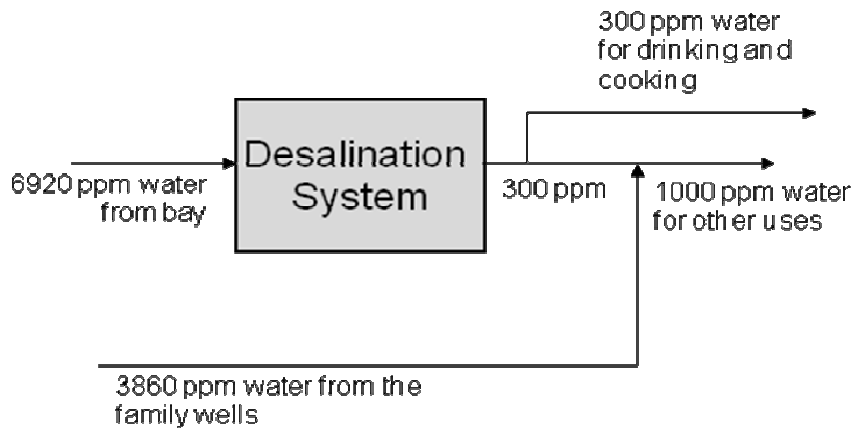
#### *1.1) Optimizing the usage for reducing plant capacity*

It is uncommon for a person to consume more than ½ a gallon per day. Most of the water purchased by the villagers is, hence, being used for cooking, cleaning, bathing, laundry and so on. Some of these applications like cleaning, laundry and bathing do not require the purified water from the pumping stations. Also, the pumping station water is a bit on the saline side to drink (650 ppm in Phaeton). Figure 1 shows a schematic of the pattern of usage of the pumping station water.



**Figure 1: A simulation of the usage pattern of water in a household in Paulette/ Phaeton.**

We propose a scheme (Figure 2) by which we will design a purification system to produce water at a salinity of 300 ppm. Some of this 300 ppm water will be mixed with the local family well water (3860 ppm) to produce 1000 ppm water. For all uses other than drinking and cooking, the 1000 ppm water can be used. The 300 ppm water can be used for drinking and cooking.



**Figure 2: Scheme to produce two grades of water for different usage**

For this scheme we calculated the capacity of the unit required for Paulette to be 26 m<sup>3</sup>/day and Phaeton to be 36 m<sup>3</sup>/day. All detailed calculations are mentioned in Appendix A. We are able to reduce the plant capacity required from 30 to 26 m<sup>3</sup>/day by the proposed scheme.

## 2) Possible desalination technologies

During the course of this project we have to constantly remind ourselves that there are many factors which will influence our final decision about which technology needs to be selected for Paulette and Phaeton. We believe the important criteria for selecting the technology include:

- How complex is the technology to implement?
- How appropriate is the technology for small scale units?
- Is the system run using electricity, mechanical energy or thermal energy?
- Is this source of energy readily available for use?
- How energy efficient is the cycle?

Various desalination technologies including reverse osmosis (RO), electro-dialysis (EDR), vapor compression distillation (VCD), multi-stage flash (MSF), multi-effect evaporation (MED), humidification dehumidification desalination (HDH) and solar stills were considered. Table 1 illustrates the pluses and minuses of these technologies for our application. ‘N’ stands for neutral in this table.

**Table 1: Pluses and minuses of various desalination technologies**

Criteria	Complexity	Appropriate for small-scale	Availability of Energy type	Energy Efficiency
RO	-	++	-	++
EDR	-	-	-	++
VCD	N	++	-	N
MSF	-	--	-	-
MEE	-	--	-	N
HDH	+	++	+	-
Solar still	++	++	+	--

Based on these observations we decided to study only the following three technologies for cost and energy requirements – RO, VCD and HDH.

### 2.1) Reverse osmosis

RO has the highest installed capacity for very small scale applications (<100 m<sup>3</sup>/day). It also is most widely used for brackish water application like ours. For a small

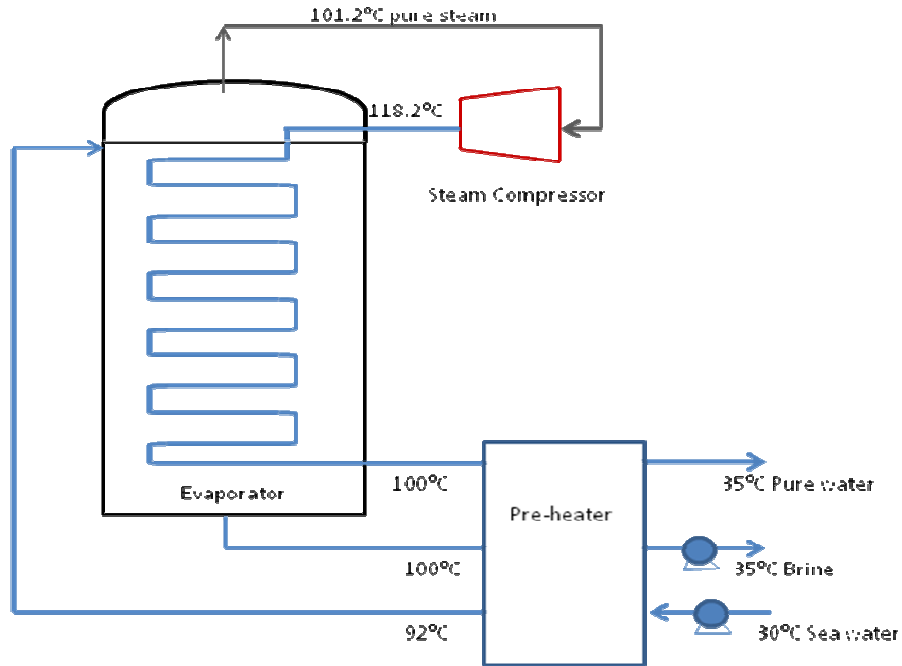
scale unit operating at a feed water salinity of <8000 ppm, the energy consumption is around ~7 kJ/kg. This value was reported by Glueckstern et al. (2001). We have calculated (Appendix B1) the energy demand to be ~2kW<sub>e</sub> for the 26m<sup>3</sup>/day plant in Paulette.

Companies like TSG water resource supply units of this size for 70,000 US \$. Their profit margins are quite big. To avoid this huge initial investment, we have selected vendors who will supply cheaper components. We will assemble these together at the sites in Haiti. Our analysis shows us that the total capital cost can be brought down to ~12460 US\$. Details of this cost analysis and all associated brochures and purchase orders are attached in Appendix B.

### 2.2) *Mechanical Vapor compression:*

Mechanical vapor compression distillation or MVC has been used widely for small scale desalting applications. The heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler. A basic example of this system operating at atmospheric pressures is illustrated in Figure 3. As can be seen from the figure, the main components required for this process are an evaporating chamber, a steam compressor, pumps and the heat exchanger for preheating. Buros [2000] has reported that these mechanical vapor compression systems are ideal for capacities ranging from a few hundred litres to several m<sup>3</sup>/day. These are very commonly used in resorts and drilling sites. They are simple to operate and reliable in operation. The energy consumption numbers for the same is around ~35-40 kW<sub>e</sub>.h/m<sup>3</sup> (Spiegler and El-Sayed, 1994).

For the 26 m<sup>3</sup>/day system, the total power of the steam compressor required will be ~40kW. The cost of MVC desalination units of these size has been reported to be around 1-3\$/m<sup>3</sup> (Semiat, 2000). However, the use of this technology for our application will involve import of the steam compressor to Haiti. Also, we will have to provide support in setting up the plant. The evaporation chamber and heat exchangers can be manufactured locally. Localities can be trained to maintain the plant. In later sections, we explain how this technology can run using a renewable power source.



**Figure 3: Vapor compression Distillation**

For the purposes of obtaining a cost for these systems, we had written to Norland International Inc. which is a world leader in small-scale MVC units (1500-10000 gallons/day). The quotation they had sent to us is attached in appendix C. The cost of their system is 121 k US\$ for a 3000 gallon/day unit.

### 2.3) Humidification dehumidification desalination:

The village of Source Philippe is a small island off the coast of Haiti, some 50 kilometers from Port-au-Prince. A solar distillation unit which produces 1100 litres per day was setup in 1969 (Alward & Lawand, 1980). This was build with minimum import of materials. Most of the construction was done by the local people (Figure 4). This experience has brought to light some of the problems with solar still systems for applications like ours. The most major of the drawbacks is that the cost of water production was high. Alward & Lawand (1980) claim that this cost was higher than the pump water cost but lower than the cost of alternate systems. The whole capital cost was funded by charitable organizations and the operational cost was borne by the villagers.

However, in recent years an alternate technology (to solar stills) which has higher efficiency has emerged. This is called the humidification dehumidification (HDH) technology. The main technical drawback of the solar still is that the various functional processes (solar absorption, evaporation, condensation, and heat recovery) all occur

within a single component. By separating these functions into distinct components, thermal inefficiencies may be reduced and overall performance improves. This separation of functions is the essential characteristic of the HDH system. Figure 5 illustrates a simple HDH system. The main components of HDH includes the solar collector for heating air, the coiling coil for condensing water from the humid air, the packed bed for humidification and water pumps for circulation.

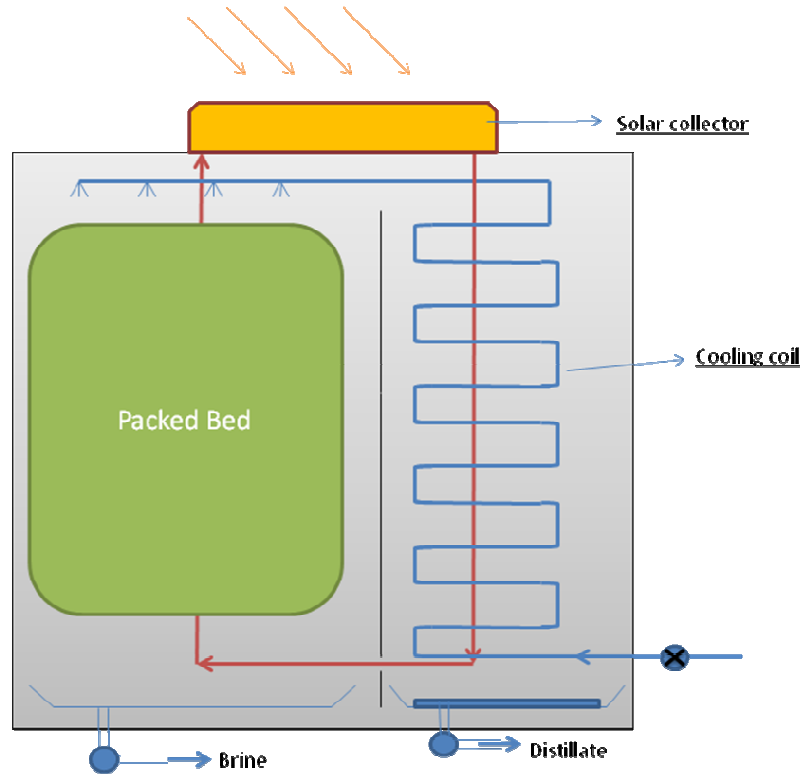


**Figure 4: Fisherman of Source Phillip working on the 300m<sup>2</sup> solar still installation**

For a 26 m<sup>3</sup>/day system, the total heat input required will be around ~230kW. The cost of HDH desalination units of these size has been reported to be around 4\$/m<sup>3</sup> (Muller-Holst, 2007). This also factors in the capital cost. If the capital cost is provided by an outside agency, the cost-to-villagers will be considerably low. The use of this technology for our application will involve import of the glass panels to Haiti. Also, we will have to provide support in setting up the plant. The solar collector, packed bed and the cooling coils can be manufactured using locally available materials. Localities can be trained to maintain the plant. The maintenance operations are considerably simpler than for other technologies. There is also no need for pre-treatment. However, there is not much field experience for these HDH units.

We should also note that because of the relatively lower energy efficiency, it is not a good option to run these systems using fossil fuels. In section 3.1 we discuss the option of using solar energy to power these systems.





**Figure 5: Humidification Dehumidification Desalination**

Table 2 summarizes the amount of energy required for each of the technologies we have discussed in this section. Further, the equipment cost has been calculated and it is observed that RO has the least equipment cost. HDH is the easiest to operate and maintain. However, we have to take into account the fuel cost and the fuel system cost. This is detailed in the next section.

**Table 2: Energy required for various desalination technologies (for 26m<sup>3</sup>/day)**

	<i>Energy input required</i>	<i>Capital cost (US\$)</i>	<i>Level of Maintenance required</i>
<b>Reverse Osmosis</b>	2 kW <sub>e</sub>	12,460	High
<b>MVC</b>	40 kW <sub>e</sub>	363,000	Medium
<b>HDH</b>	230 kW <sub>th</sub>	273,350	Low

### 3) Possible energy sources

Our various options for energy systems include diesel engines, wind mills, solar flat plate collectors and kyte technology. The diesel engines, the wind mills and the kyte technology will be designed to supply mechanical or electrical energy to RO or MVC

systems. The solar flat plate collectors are meant to supply energy to the HDH systems. To find the most comprehensive water purification system for the villages in Haiti the following questions about the energy supply system should be considered.

- Is the form of energy readily available?
- Is it the direct form of energy desired or is there a conversion step?
- Can this energy system be built using indigenous material?
- Can this energy system be maintained easily?
- Is it polluting and will it upset the local ecology?
- Is it sustainable in the long run?

### 3.1) Solar flat plate collectors:

Solar energy is the source of almost all energy sources on earth. The total amount of solar energy hitting the earth exceeds humans demand by a factor of 8000. Capturing the thermal energy could provide the necessary heat for the desalination technology. Flat plate collector are simple devices which serve this purpose. They require minimal raw material. The main component which might not be locally available for this purpose will be the glass glazing. However, these are quite inexpensive in the US and can be imported as was done for the project in Source Phillip 40 years ago.

**Table 3: Solar insolation data for Haiti (monthly average)**

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m <sup>2</sup> /day	4.17	4.81	5.48	5.82	5.84	6.35	6.29	5.99	5.65	4.98	4.24	3.92
Clearness, $\bar{0} - \bar{1}$	0.55	0.56	0.57	0.55	0.54	0.58	0.58	0.57	0.57	0.56	0.54	0.54
Temperature, °C	23.01	23.22	23.75	24.28	24.79	25.11	25.01	25.18	25.13	24.89	24.28	23.45

Table 3 shows the solar insolation data in kWh/m<sup>2</sup>/day. As it can be seen from this data, the insolation is on an average above 5. The average day temperature hovers around 23-25°C. This is good enough for our application. For a 26m<sup>3</sup>/day HDH system an energy input of 230 kW is required. Assuming a solar collector efficiency of 50%, the required area of solar collector was calculated to be 730m<sup>2</sup> (27m x 27m). Commercial solar air heaters are available at 500 US\$ for 2m<sup>2</sup> of solar collector area. This reflects in a collector cost of 182.5 k US\$. However, we expect the cost to be lesser if built locally in Cap Haitian or port-au-prince. Further, the solar collector cost alone mounts to 0.96 US\$/m<sup>3</sup> of water produced.

### *3.2) Diesel Engine*

A classical combustion engine is a very traditional, conservative but also very reliable energy converter. Large truck engines provide peak efficiencies of around 45% (Ref: EPA website) and they are quite flexible in processing other fuels such as plant oil as well. They are so widely used that the technology can be handled in most parts of the world.

In an engine, the chemical energy of the fuel is being burned in the engine to produce mechanical power. Diesel is available on the Island of Haiti for a price between \$2.5 and \$3 per gallon. For the long term a better option will be to power the diesel engine with pure plant oil (Awkins et al., 2005). Installing and maintaining a Diesel engine is certainly within the scope of Haitian workmen. Considering pure plant oil (PPO) as a possible option, the process of planting and squeezing, for example, canola crops is very easy and can be done in Haiti.

### *3.3) Wind Energy*

The kinetic energy of the moving air has to be captured and transformed into useful work. For our application, we consider two technologies as promising to cost effectively provide the necessary power for RO and MVC units. These are low spinning windmills and kite technology. Both can be built and maintained by local people.

The theory by Alfred Betz (year) shows that it is physically not possible to capture more than 59% of the wind power. In practice that is even less. Most advanced turbines reach efficiencies of ~48%.

#### *3.3.1) Wind Mills:*

Low spinning windmills use drag mechanisms to harness wind power and they have maximum efficiencies of ~30%. These windmills (often called “American Windmill”) are possible devices to be used to pump water, create pressure or supply mechanical energy.

#### *3.3.2) Kites:*

Wind turbine technology (different from windmills) reaches higher efficiencies, but is too complex to be designed or manufactured in Haiti. Kite technology on the other side combines high efficiency and locally manufacturing possibilities. The concept of energy production using kites is very new. The most active R&D companies in this field are KyteGen, Skysail and Makany power (subsidiary of Google). This technology is based on

the concept that the outer 20% part of the wind turbine blade gives most of the energy (Figure 6) and also that the wind speeds are much higher at a higher altitude (above 100 m). These heights can be easily reached by the kites.

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Please see Fig. 5 in Canale, Massimo, Lorenzo Fagiano, and Mario Milanese. "Power Kites for Wind Energy Generation." *IEEE Control Systems Magazine* / 27 (December 2007): 25-38.

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[http://www.youtube.com/watch?v=Zl\\_tqnsN\\_Tc](http://www.youtube.com/watch?v=Zl_tqnsN_Tc)

### **Figure 6: Concept of kite power generation.**

Figure 7 (a) shows a kite used for wind-surfing and Figure 7 (b) shows a Kite Power plant Prototype of KyteGen Pvt. Ltd. The shown prototype can create 40KW at wind speeds between 15m/s and 25m/s. At lower wind speeds it is proportionally less. [Appendix D]. Construction plans for kytes exist as open source and easy to manufacture. Provided with appropriate fabrics, kites can be manufactured by local sewers.



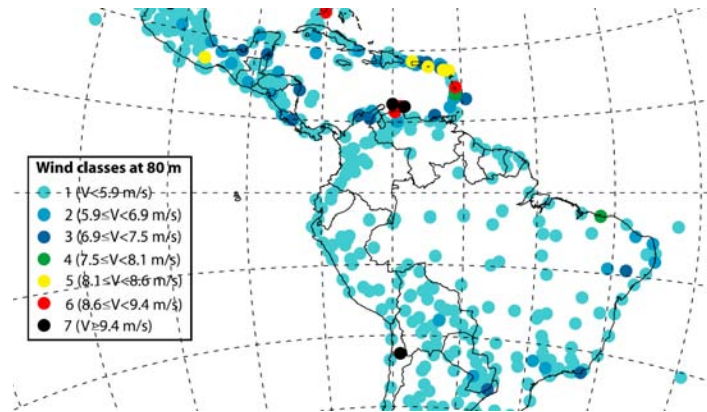
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Please see Fig. 2 in Canale, Massimo, Lorenzo Fagiano, and Mario Milanese. "Power Kites for Wind Energy Generation." *IEEE Control Systems Magazine* 27 (December 2007): 25-38.

### **Figure 7: (a) Kites used for surfing; (b) Kites used for power generation.**

The most trusted global wind energy evaluation has been performed by Stanford University (author, 2005). Locations with annual mean wind speeds  $> 6.9\text{m/s}$  at 80m height are considered as suitable for low cost wind power production. Approximately 13% of all wind reporting station fall under these criteria. According to Figure 8 ((author, 2005), Haiti is one of the more windy sites in middle and south America with a mean annual wind speed of around 8 m/s. An analysis of possible sites in Phaeton and Paulette should be undertaken since a desalination plant powered by wind energy makes sense in the region. The two chosen technologies can both be manufactured and maintained in the

region. Minimal amounts of high tech materials, competencies or production tools are necessary.



**Figure 8: Wind energy map for South America**

### 3.4) Comparison

The power production prices for each technology have been calculated [Appendix D]. Table 4 shows the results in terms of costs per  $m^3$  of fresh water produced. As can be observed from the table, based on cost alone, the generator run using diesel or plant oil can be eliminated. Kite technology presents a very unique and viable option as it is both inexpensive and can be made locally. However, this technology requires that the localities are trained for operating the kite technology in a systematic way. For HDH, because the efficiencies are much lower than RO or MVC, solar is the only energy option. The advantage of using flat plate collectors for this application are that they are simple to construct and can be done so almost fully using local materials.

**Table 4: Energy system cost**

<i>All values are in <math>\\$/m^3</math></i>	<i>Generator (PPO)</i>	<i>Windmill</i>	<i>Kites</i>	<i>Solar thermal</i>
RO	0.20	0.03	0.03	NA
MVC	3.74	0.53	0.50	NA
HDH	NA	NA	NA	0.96

## 4) Recommendations

Based on several criteria listed in the previous sections we have carefully shortlisted our desalination and energy system options. In this section, we intend to select the best of those options based on the total cost, level of maintenance and skill required. Table 5 shows the total cost and other details of all the options evaluated. It should be noted that the villagers are currently paying  $1.27\text{US}\$/\text{m}^3$  for the water from the pumping station.

**Table 5: Evaluation matrix**

	<i>RO with Kyte power</i>	<i>Solar HDH</i>	<i>VCD with Kyte power</i>
Equipment cost (US \$)	12,460	273,375	363,000
Energy system cost (US \$)	5694	182,250	94,900
Total Cost (US\$)	18,154	455,625	457,900
Water cost (US\$/m <sup>3</sup> )	0.096	2.4	2.412
Cost-to-villagers (US\$/m <sup>3</sup> )	0.03	<0.96	0.5
Level of Maintenance	High	Low	Medium
Skill required	High	Low	Medium

As can be observed from the table, the water cost (US \$/m<sup>3</sup>) is minimum for RO systems. But this system has the following disadvantages: regular membrane replacement (translates into regular imports) is required; sophisticated maintenance issues to be handled by localities; highly skilled labor is required to operate these RO units;

MVC technology with kite power also presents an interesting option. The initial investment is heavy in this case. The kite technology requires some skilled labor. This translates into a need for us to train the localities in handling these kites.

Solar HDH technology also involves a heavy initial investment. The “cost-to-villagers” is, however, still lower than the current cost of water in Paulette and Phaeton. This assumes the initial investment is paid by Mercy & Sharing or any other charitable organization.

Given the fact that there is very less skilled labor that we can make use of and the fact that negligence among localities is very high (even hand pumps for wells are un-repaired), we recommend that solar HDH systems might be best option for this application. However, if there is a lack of funds for initial investment, Mercy & Sharing

should considering building a smaller HDH unit which will, perhaps, serve a school or a part of the community atleast.

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