Water Pump Team Reflection Report

Authors: Michael Liu, Patrick Farnham, Weiling Xu, Dominick Amador

AguaClara Reflection Report

Cornell University
School of Civil & Environmental Engineering
Ithaca, NY 14853-3501

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Abstract

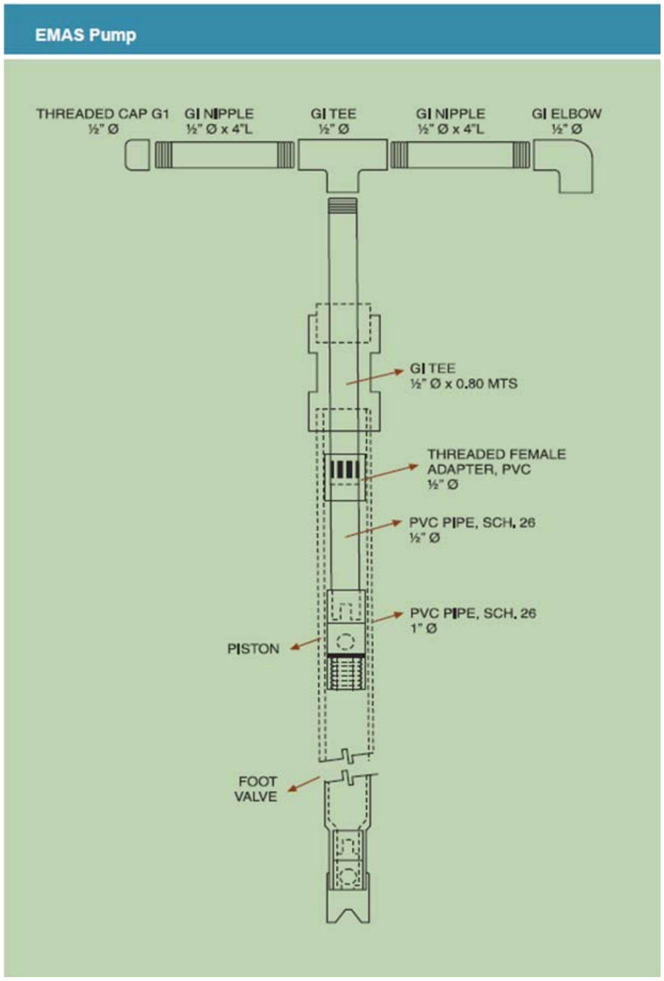
The purpose of the water pump team's research is to design a manual water pumping system that can be used by an operator to lift water two to three meters from the settled water channel to the chemical stock tanks while striking an optimal balance between cost and efficiency. We have done research on several types of water pumps and narrowed our options down to foot- and arm-operated piston pumps and diaphragm pumps. Mechanical feasibilities, simplicity of repair, ease of access to base materials in Honduras, and possible failure modes are considered. In the future, we will analyze the discharge rate of the pump and head loss using MathCAD. If the conclusion is made that our pump does not significantly outperform or cost less than commercially available designs, we will select the most viable pump on the market.

Introduction

The goal of the water pump research is to either find or design and fabricate a human-powered water pump that is capable of lifting water two to three meters using as little effort from the operator as possible.

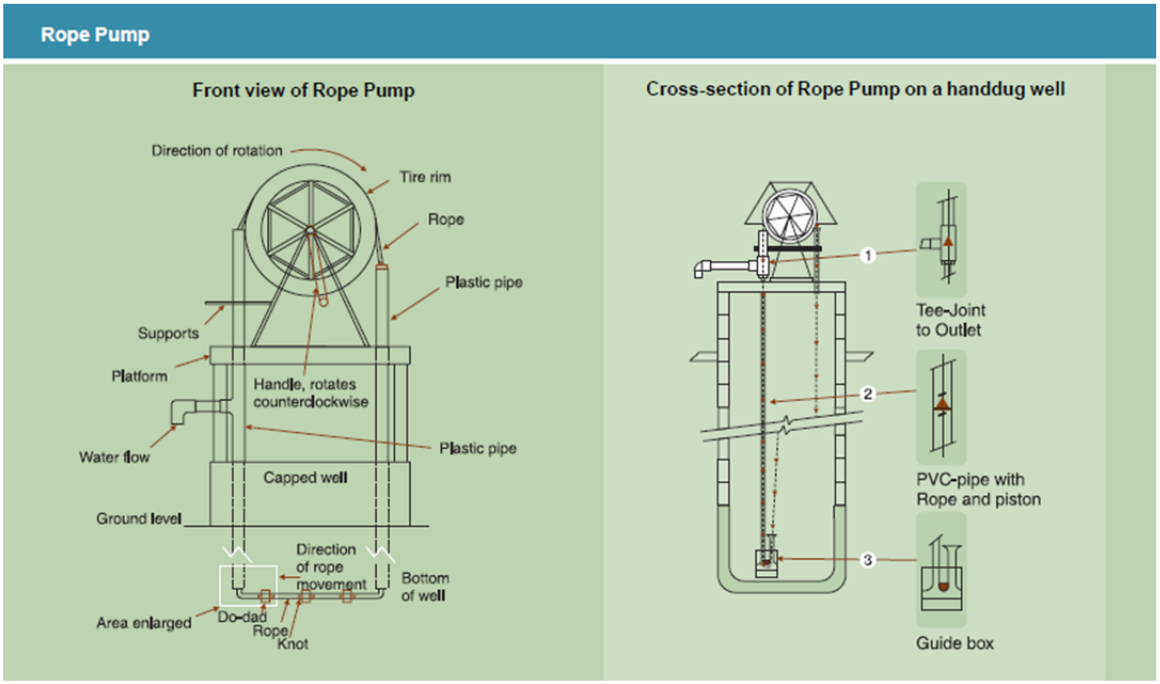
There are two designs in particular that are currently under consideration by AguaClara engineers in Honduras. Both are detailed in a document issued by the Water and Sanitation Program (WSP) in 2004.

The first, the EMAS-flexi Hand Pump, consists of a small sliding PVC piston assembly that can achieve a discharge rate of 10 liters per minute. It is pictured below in an image taken from the WSP document.



This relatively low flow rate would likely be prohibitive, requiring a continuous operation time of over 20 minutes to fill a 55-gallon Aguaclara stock tank. Some positive attributes of the EMAS pump include its low price (Honduran materials would average 10 USD), ability to overcome more than ten meters of elevation head, and infrequent replacement required (it is designed to have a 4- to 9-year operational life).

The other pump in consideration is the traditional rope pump, pictured below.



This pump is cited by the WSP to have a cost of over 100 USD, plus annual maintenance and repair costs. Though consistently higher flow rates could likely be achieved with this pump relative to the EMAS model, the problem of space constraints renders this pump too clumsy for use in a typical Aguaclara plant.

Other pump designs do exist, however, and have not yet been considered for use by Aguaclara. Two designs in particular that have appealed to our team from the beginning of our research are the lever- and pedal-operated PVC piston pumps.

When pedal-operated, the piston pump design is referred to as a "treadle pump", and is pictured below. All design pictures and parameter citations for this pump have been taken from a synthesis report compiled by the International Programme for Technology and Research in Irrigation and Drainage in 2000.

Figure 1: Treadle pump operating principles

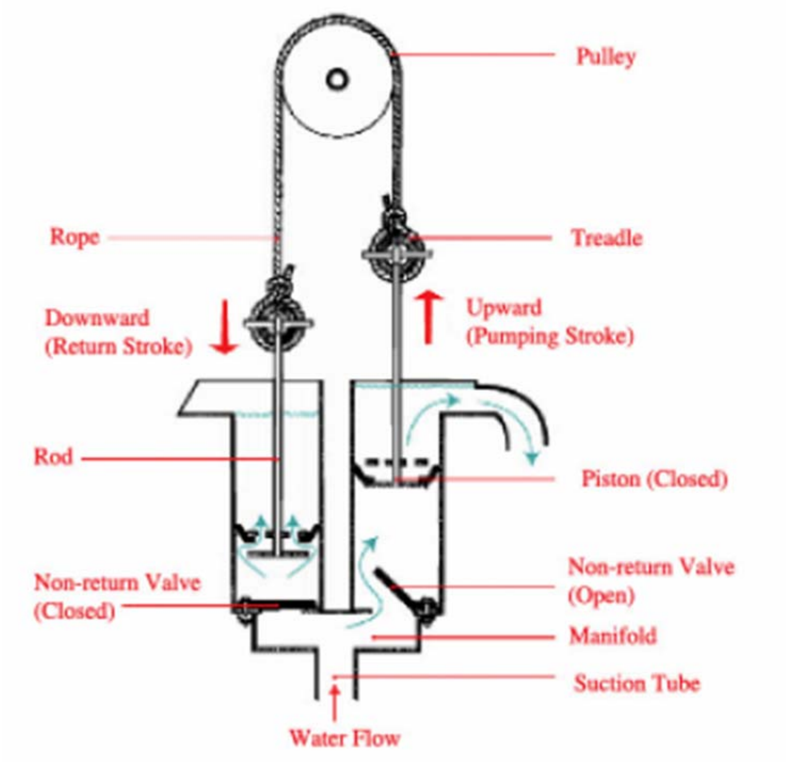
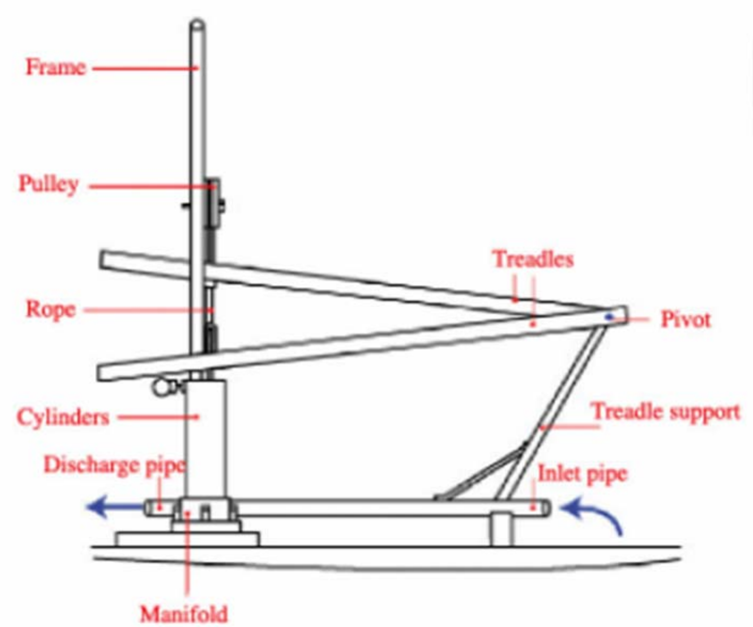


Figure 2: The basic components of a treadle pump



Treadle pumps built in this style for similar rural applications have been shown to achieve discharge rates of 1.5 liters per second for two meters of head, which far exceeds that of the

EMAS pump. Commercially-available treadle pumps, such as the KickStart Moneymaker pressure irrigation pump, are already used in developing regions for irrigation purposes, but may not be easily adapted for our usage. The Moneymaker in particular was found by an MIT student study in 2005 to have a consumer cost of 50USD, which is a bit higher than what we're aiming for.

We are unable to find existing information on lever-operated PVC piston pumps, but are confident that the basic design of a treadle pump could be easily modified to include a simple pivoting lever or possibly a rotary assembly, which would be a bit more difficult.

Experimental Design

In order to determine the optimal pump design for transporting water two to three meters in elevation, it was first necessary to develop the general style of delivery. When first approaching this idea we had several specific points on which we wanted to focus to create the ideal pump for the job. For this particular project, we decided to focus on the following constraints while optimizing outflow:

- Head change – 2 or 3 meters
- Self-Priming
- Human powered (ergonomic)
- Easily constructed, maintained, and repaired in Honduras
- Process easily understood and performed

There were a variety of systems we evaluated, but we found that certain restrictions inhibited these designs from being a part of AguaClara. The vane pump is an example that we looked at extensively but concluded we could not use because of difficulties involved in price, construction, and repair. We have concluded that, due to these restrictions (mainly those imposed by plant location), the optimal systems that would best serve our needs are the lever-powered piston pump, the treadle pump, and a diaphragm pump. Each of these bring their own advantages and disadvantages, and over the next few weeks we will be finishing up MathCAD modeling and possibly conducting experiments to further narrow down our options.

At this point we have been working to develop a system of equations to model our designs such that we can use them to optimize several parameters and ensure that we attain the desired flow rate. The variables of the system we focus on in this case are as follows:

- Reservoir Diameter
- Outflow Pipe Diameter
- Piston material and configuration (or membrane material)
- Piston range of motion
- Cycle Rate

In order to develop relationships between these variables, we are using MathCAD to relate human-generated forces and head loss to the energy equation.. Here is the solution process that we are going through to create our pump design:

1. Given the human operator power of 75 W we calculate for pump discharge with:

$$Q_{pump} := \frac{P_{applied}}{\gamma_{water} \cdot \Delta z}$$

2. With the flow rate calculated, we use the head loss functions from the Fluids Function reference and calculate for the head loss throughout the whole pumping system.
3. We analyze the head loss equations to find proper diameter piping we could use that would be financially viable and that would give us low head loss
4. We then calculate for the stroke length to find how large the pump chamber should be:

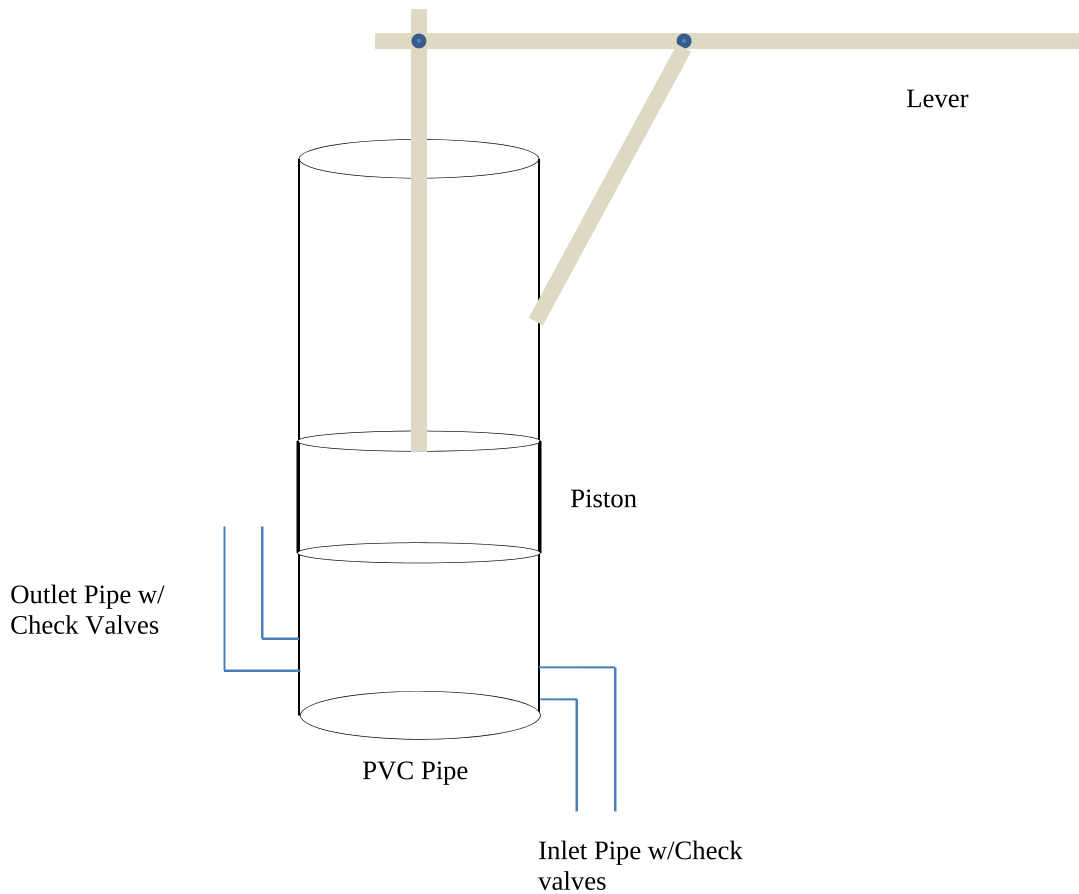
$$L_{Stroke} := \frac{Q_{pump}}{A_{chamber} \cdot C_{cadence}}$$

5. Calculate for lever length:

$$F_{operator} := \frac{P_{operator}}{L_{lever} \cdot C_{cadence}}$$

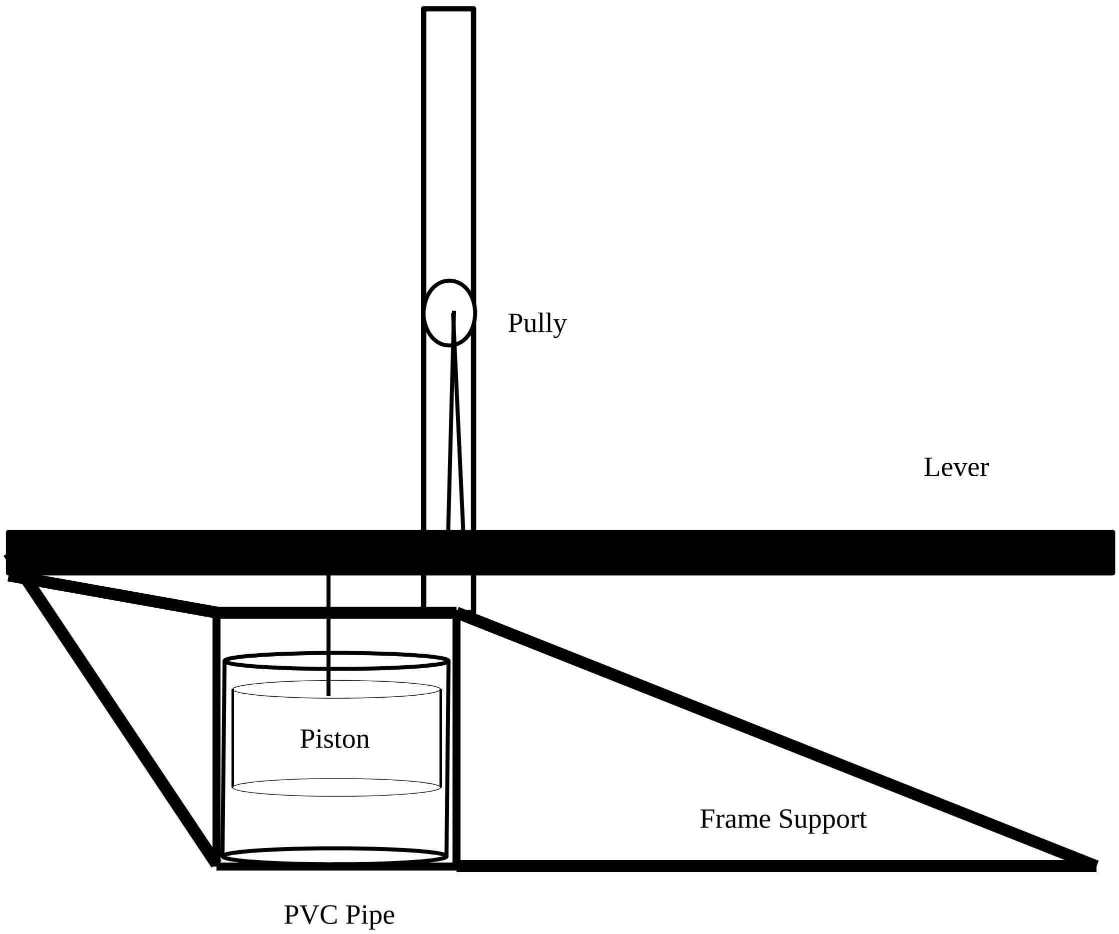
The following are rough sketches of pump systems we are working on:

Lever Piston Pump



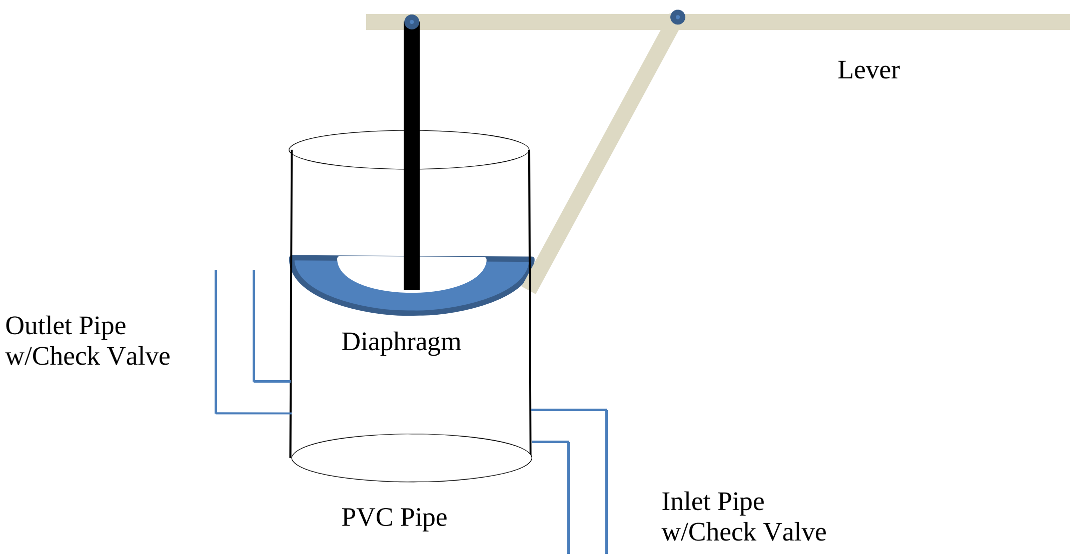
In this pump design the operator pulls the lever down, which in turn lifts the piston up. This creates a pressure difference, bringing water into the PVC pipe from the inlet pipe. When the operator pushes the lever back up, the water is pushed through the outlet pipe.

Treadle Pump Design



In this pump design the operator steps on the levers, pushing the piston up and down. The concept works similarly to the lever pump design, but is foot-operated.

Diaphragm Pump



This pump is designed similarly to the Lever-Operated Piston Pump, with the exception that the piston is replaced with a diaphragm membrane. Pressure difference is then created not by a moving piston but by the flexible membrane in its place. Note that due to pressure the diaphragm will deform differently than how it is drawn in the diagram.

Materials

In choosing the materials for our pump, ease of access in Honduras, robustness, and durability of the system are our main concerns. For the frame support and lever systems, the material options included steel, wood and aluminum. Considering the fact that a strong support will be needed for both the lever piston pump and treadle pump such that the variability of the angle between the lever and piston is minimized between each stroke, and taking price into account, we think steel will be a better choice. For pipe and chamber materials, due to economic concerns, we think PVC will be the best choice by far, even though it has a higher friction. Thus, we have decided to use a mixture of PVC pipe and steel for the construction of both the lever piston pump and treadle pump. In our initial designs the pump casing will primarily be made of PVC pipe whereas the frame support and lever systems will be made of steel.

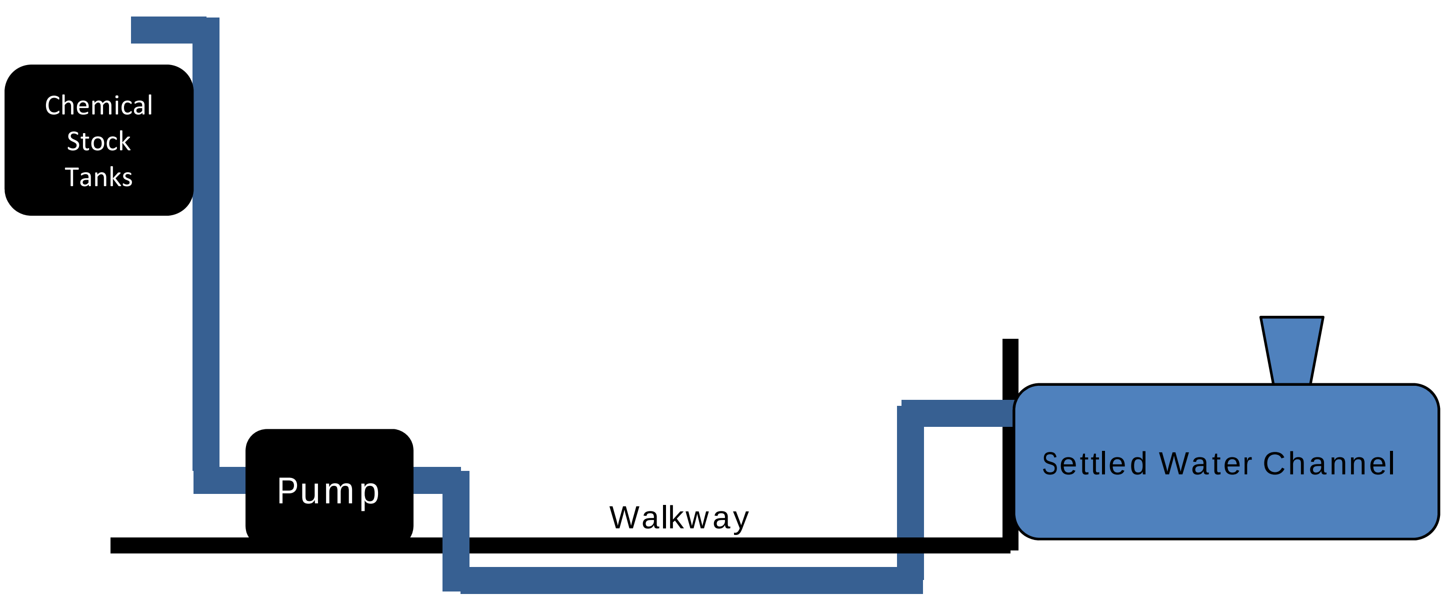
In order to keep our aim at the ease of manufacturability in Honduras, constraints limit the membrane material to only a few options in the diaphragm pump. The difficulty of finding a working membrane is that in order to attain the best results the diaphragm pump has to have a good degree of elasticity, while at the same time it has to have the ability to retain large pressure force over time. Our initial choice for the membrane, due to its availability, was an inner tube from a motor vehicle's tire. We could also use the materials from swimming or rafting tubes.

Inspired by most materials used for commercial diaphragm pumps, we did a research on rubber and found that butyl rubber has been used in many applications requiring an airtight environment. It is used for the bladders in basketballs, footballs, soccer balls and other inflatable balls. Subsequently we believe that using a soccer ball or basketball (which can be easily found) will allow us access to a membrane that will serve our purposes in the diaphragm pump. Additionally, if this system works well, the pump can be fixed in Honduras if there is a problem with its membrane due to the ease of attaining such materials.

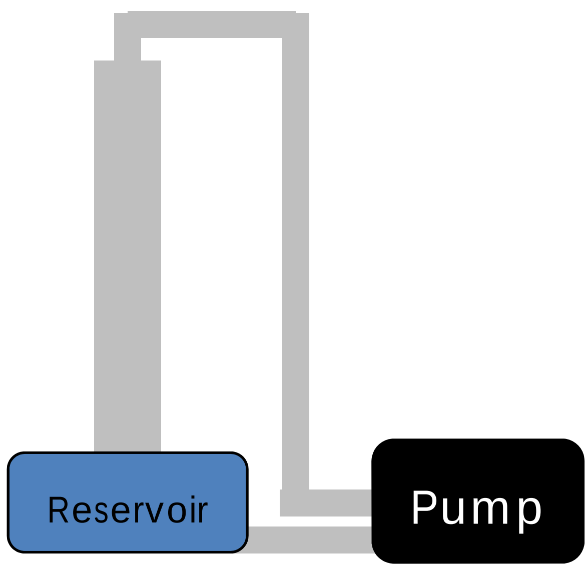
Silicon is another possible material that was looked at for the membrane in diaphragm, but it is difficult to find and thus such a material is not the focus of our design.

In the future when we have finalized our design, we will do another thorough research on materials and see if there are any better options.

Experimental Apparatus



When it comes to developing a way to test our system, we need to develop a way to model the overall AguaClara plant's parameters in a much more confined system. In this case we are planning on developing a way to transfer water from a singular reservoir in a circular system so that there never needs to be any transferring of water from the final tank to the initial. Although we have yet to determine the exact dimensional specifications to model equivalent, we plan on being able to model this by lowering pipe transfer diameter to accommodate the head loss within a shorter length of pipe. Below we have attached a preliminary drawing to show an initial concept for the system.



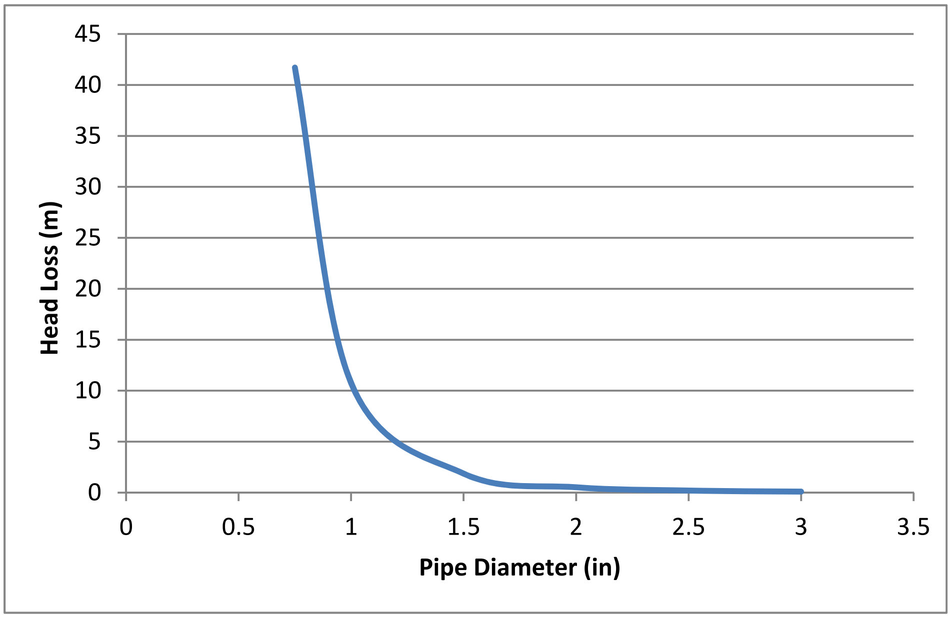
Preliminary Design Results

Using the pump equation we have calculated our pump discharge as a function of operator power input and effective head (including losses):

$$Q_{pump} := \frac{P_{applied}}{\gamma_{water} \cdot \Delta h} = 1.78 \cdot \frac{L}{s}$$

We calculated the varying head losses based on different system pipe sizes using the head loss equations from the Fluids Functions MathCAD file in conjunction with tabulated minor head loss values for pipe system components. We estimated a total minor loss factor for each pipe size by summing these individual losses, and then added the calculated major losses for each pipe size as well.

We graphed these losses as a function of pipe size below:



It was obvious from this graph that the losses experienced by small pipe sizes were prohibitive. We decided on 2.5 inch pipe as a good balance between minimization of losses and materials costs, because the calculated head loss of 0.149 meters represents a loss of only about 6% of the elevation head.

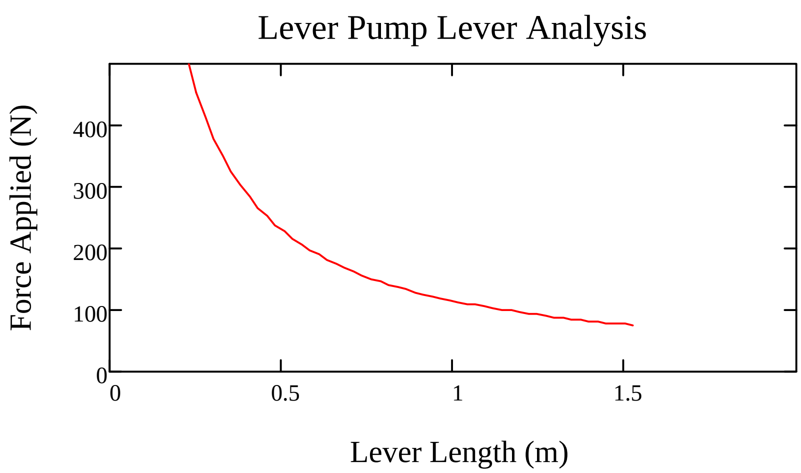
These head losses were actually required to be iterated, because major losses are a function of velocity, which is in turn a function of discharge rate itself. We performed the iteration using MathCAD and settled on the values appearing in the graph above. We used nominal diameters in our calculations; thought actual inner diameters vary from these numbers. However, because the actual ID's are scaled proportionally to nominal diameters, the actual head loss curve would not differ much from the one above.

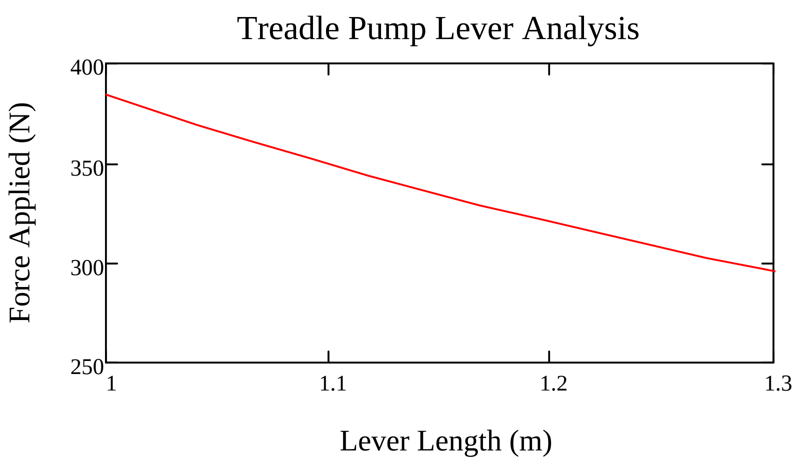
Our next step was to get a rough estimate of how large our pump chamber was going to be. To do this we estimated the stroke length of the piston with this equation:

$$L_{Stroke} := \frac{Q_{pump}}{A_{chamber} \cdot C_{cadence}} = 7.684\,in$$

We estimated our cadence to be 30 cycles per minute, assuming that would be a comfortable rate for the operator.

Our last variable was to calculate the lever lengths of the Lever-Operated Piston Pump and the Treadle Pump. Here we used a moment balance around a pivot point for both pumps to create a graph between the forces that the operator must apply to the lever arm.





Future Work

Detailed Task List:

1. We will need to perform analysis of the flow within our treadle and diaphragm pumps using MathCAD in conjunction with fluid mechanics equations.

2. After using this analysis to approximate numerous parameters including frictional head losses, required operation rate (cycles per minute), and potential flow rate, we will assess the viability of each pump option.
3. At this point, it will be necessary to determine whether we can improve on existing pump designs, balancing cost and performance.
4. After completing a design for each viable pump, we will assemble a complete materials list and obtain any missing parts.
5. Construction of the prototype will commence as our team attempts to build our design with available materials.
6. After construction of our prototype pumps we will test the pumps, identify mistakes in the design and make changes to the prototypes accordingly.
7. After prototypes have been finalized, we will test for efficiency and effectiveness and choose the optimal pump.

Team Reflections

The past several weeks have been marked by alternating periods of excitement and frustration. In the early stages of brainstorming for the basic pump type, we cycled through numerous designs before settling on a choice between a hand- or foot-operated piston pump and a diaphragm pump. At a superficial level, piston and diaphragm pumps seemed like foolproof designs, as they are mostly free of moving parts and easily operated.

However, further analysis proved frustrating. Our team contains a mixture of students who have not taken fluid mechanics and students who took fluid mechanics over a year prior to this semester, so our grasp on fundamental equations is tenuous at best. Modeling the flow through each pump design is dependent on knowledge covering several areas of fluid mechanics and will need to be undertaken using class notes from CEE 4540 and a quality textbook.

Another source of early concern was the potential pricing of materials; advertised prices in the McMaster-Carr catalogue seemed prohibitive to the construction of our pump due to their desired material pricing when it came to both steel and PVC pipe. However, we were able to circumvent this issue by seeking our steel supply from Ben Weitsman & Son Inc. who was able to provide us with all of our steel at nearly twenty percent of what we had previously planned.

In the future we plan to further develop our analysis of each of the pump designs such that we have a mathematical basis from which to optimize output in a manner that is both efficient and ergonomic to the operator.

Once final values of flow rate have been calculated and we have designs for the pumps themselves, we will be able to compare the pumps directly to those which are already on the market. At this point we must additionally take into consideration manufacturability and maintenance as well as the criteria mentioned above and make the decision as to which of our options, whether it be one of our designs or one of the options readily available on todays market, would be the most beneficial to the AguaClara project as a whole.