



# EXECUTIVE SUMMARY

This report is a culmination of a semester's efforts of four Michigan State University mechanical engineering students on a global-scale humanitarian project. This project, which entailed the refinement of a treadle pump design, was brought forth by The Appropriate Technology Collaborative. The Appropriate Technology Collaborative (ATC) is a non-governmental organization (NGO) that aims to create sustainable technologies to improve the lives of low-income people across the globe.

ATC had previously developed an instruction manual that detailed how to construct a treadle pump, which had been downloaded over 3,500 times worldwide. A treadle pump is a human-powered pump that helps farmers of developing nations to irrigate their crops during the dry season. Without a treadle pump, farmers who wish to irrigate their fields are forced to perform the daily labor of walking to-and-from the nearest water supply while burdened with half of their body weight in water. This task can take over half of a workday and is incredibly hard on the malnourished bodies of impoverished rural farmers.

Observing the incredible response to the diffusion of the original ATC treadle pump led to a desire to refine the design to better serve its target market. ATC identified areas that had proved to be shortcomings of the original treadle pump design. ATC's design request was to take the original design and improve upon its ergonomics, durability, and portability while allowing it to be manufacturable in developing countries.

The MSU team began its task by building a base of knowledge on the topic. After defining their target market as India, an anthropological study was completed to better understand the daily lives of the people. A benchmarking study was also completed to establish the market standard for treadle pumps. Once a clear picture of the ideal treadle pump had been established, a series of design specifications were examined and weighted. These design specifications were utilized throughout the remainder of the design process to direct the design of the treadle pump. The MSU team also constructed the original ATC model, following the steps laid out in the construction manual. This was done to gain an understanding of the operation of the treadle pump as well as identify any additional areas for improvement.

Due to time constraints, the project scope was centered on four key areas: the cylinders, pistons, seals, and the valve system. The original design used PVC cylinders with rubber valves, components that lacked basic durability and dimensional tolerance critical to the pumping operation. Improvements were made by exchanging the PVC for steel and by switching the rubber valves with spring-loaded check valves. The pistons were created to be durable and easily manufactured. Seals were selected based on material availability and functionality.

The overall improvements from the original to the new ATC design are discussed in detail in the report. Notable achievements include a 183% decrease in product weight and a 450% decrease in required operation force. The finished product could potentially transform the lives of 80% of the world's population.

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## PROBLEM INTRODUCTION

The goal of this project was to build a functional and fundamentally sound prototype treadle pump, which improved on various areas where the original ATC treadle pump was lacking. Instruction and details that were required to replicate this re-designed, re-invented treadle pump were to then be disseminated to rural farmers in Africa, Asia, and Latin America. Benchmarking, reverse engineering, and reconstruction of the original model were some of the many tools that were utilized to solve the design problem this project presented.



**Figure 1.** Completed Current ATC Pump as of 2/22/2013

The implementation of an easily produced treadle pump could change the lives of millions of poor families in rural areas of developing countries. Ideally, a treadle pump design would be manufactured locally in the major cities of developing countries and then shipped to rural farms. These irrigation pumps are stepped on like a StairMaster machine to generate a pumping action, which drives the pistons to produce water from a well, river, or other water sources.

It was desired to limit the parts of the treadle pump produced away from the rural village to: the pump cylinders, pistons, and the platform to which they mount. This would allow for numerous pumps to be manufactured in large cities of developing countries and then shipped smaller villages or surroundings countries. Affordability of the pump to meet the rural farmers' income was a must. Because there are alternative pump options available to the farmers, this working prototype would have to be competitive with other models.



**Figure 2.** MoneyMaker Max, one of the competitors used for benchmarking

To properly undertake the project, the new and improved pump design was broken down into five main components: piston seals, pistons, a valve box, piston cylinders, and a frame/base. Numerous concepts for each of these main components were considered. A selection for each component was made using the information gathered during research, benchmarking, and construction of the original ATC pump.

This report will follow the design process implemented by the MSU team during the course of the semester. The thought process behind each component selection will be discussed along with the execution and examination of the finished design.

## ATC DESIGN REQUEST

When The Appropriate Technology Collaborative tasked the MSU mechanical engineering team with the refinement of original ATC treadle pump design, they provided a list of accomplishments that they wanted to see at the conclusion of the project.



Figure 3. Original ATC Design

This list comprised of four basic portions. The first request was that the ergonomics of the original pump design be improved upon. As can be seen in Figure 3, the original treadle pump design positioned the operator approximately three feet off of the ground. This situation was not only awkward for the operator, but was also potentially dangerous. ATC also specified that the refined treadle pump design should have improved portability over the original design. As farmers are often required to transport their treadle pumps to their fields, a light and compact design would be

highly beneficial. Figure 3 shows that the original design had a large frame constructed out of angle-iron steel, a design ill suited for transportation. The third request from ATC was that the overall durability of the treadle pump be improved. Areas such as the usage of PVC for the piston cylinders and leather for the seal material were given as examples where material selection had a large impact on the durability. The final request given by ATC was that the finished product be one that was manufacturable in developing countries. This would entail gaining an understanding of the capabilities of manufacturing processes available in developing countries.

## **BACKGROUND INFORMATION**

### *i. Understanding the Treadle Pump*

Treadle pumps are human-powered water pumps used to irrigate crops in rural areas of developing countries. These pumps operate in a manner similar to a StairMaster workout machine, using the repetitive up and down motion to power a piston cylinder arrangement that pumps water.

There are two basic types of treadle pumps on the market: suction pumps and pressure pumps. Suction pumps are cheaper than pressure pumps, but are not able to push water over a significant distance. For this reason, pressure pumps are valuable to farmers who wish to irrigate a large expanse of land. The treadle pump produced by ATC is a pressure pump.



Treadle pumps have the ability to transform the live of rural farmers. The main difference between a rich and poor farmer in a developing country is access to water. With the addition of a treadle pump to their agricultural process, farmers in India have the ability to grow crops all year round, practically tripling their income.

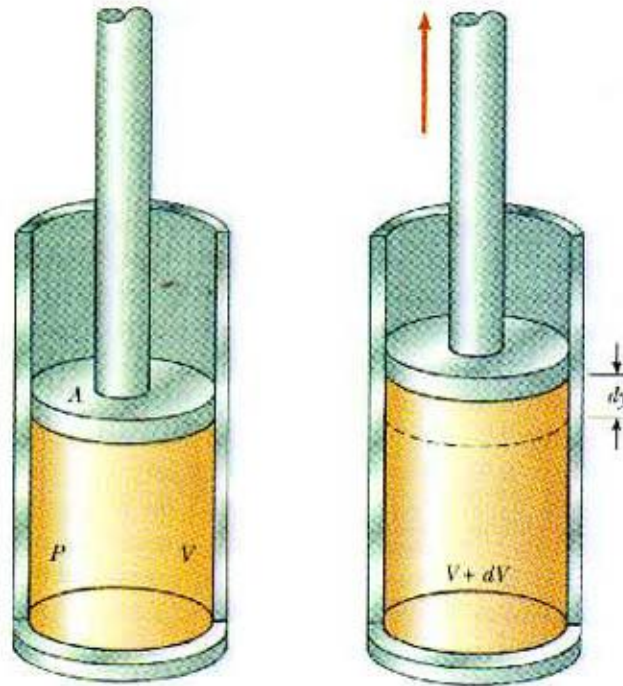
### ***How Treadle Pumps Work***

A treadle pump consists of seven main components: a drive system, treadles, piston cylinders, a valve system, piston seals, piston shafts, and a frame. To work a treadle pump an operator steps on the treadles like one would step on the pedals of a StairMaster.

A suction pump operates by sucking water up through a pipe connected to a water source. At the end of this pipe is a non-return valve that allows water to enter the pipe and stops it from flowing back into the source. When the piston is pushed down, the water is forced through a small valve in the piston to fill the space above it. When the piston is raised again, it lifts this water until it pours out over the rim of the cylinder and into an irrigation channel or tank. At the same time, more water is drawn into the space below the piston. The downward stroke of the piston once again pushes water through the small valve into the space above the piston and the process is repeated.

A pressure pump is more complicated than a suction pump, but its main distinction is that it uses pressure to push water out. The drive system takes the oscillating motion from stepping on the treadles and applies it to the piston shafts. The piston shafts, which connect the drive system to the piston seals, are then responsible for driving the pistons up and down the length of the piston cylinders. As

the pistons are brought up, the seals create suction within the piston that draws water from the source. When the pistons are pushed down, the water collected in the piston cylinder is then forced through an outtake chamber. A basic schematic of the inside of a piston cylinder is shown in Figure 4 below.



**Figure 4.** Inside view of a piston cylinder

Within a pressure pump, the direction of the water's movement is dictated by the valve system. As the water is pulled upwards, the valve system allows for the intake of new water while preventing collected water from back flowing. As the water is pushed out, the valve system allows for the water to exit the pump through the outtake chamber while preventing any water from entering the intake chamber.

Although they are not an integral part of the pump operation, treadle pump frames do have an effect on the quality of the treadle pump as a whole. Quality frames are usually lightweight, sturdy, and as low to the ground as possible.

## ii. *Benchmarking Study*

In order to determine the market standard that The Appropriate Technology Collaborative aspired to reach with its refined design, a benchmarking study over different marketable treadle pumps was executed over. Benchmarking was also utilized as a means of discovering good practices being implemented in various treadle pumps. Figure 5 shows several of the different types of treadle pumps that were investigated. Appendix I houses the benchmarking study in its entirety.



Figure 5. Various Treadle Pumps

Several different aspects of treadle pumps were investigated during the benchmarking process. Primarily aspects were the price, flow rate, suction depth, and weight. Table 1 below summarizes the main specifications of the marketable treadle pumps, which were obtained from average values.

**Table 1.** Average market standards for treadle pumps

<b>Specifications</b>	<b>Average values in the market</b>
Price	\$75.00
Flow rate	4,500 liters per hour
Max. Suction Depth	7 meters
Max. Pumping Height	12 meters
Push water distance	80 meters
Weight	20 kg
Irrigation capacity	2 acres

### *iii. Anthropological and Environmental Study*

The population of India was chosen as the primary market for this product. Upon establishing this, it became clear that the product must be suited for the size and weight of this country's population. The average adult male stands 5'5" with an average weight of 60 kg. The average adult female stands 5'0" in height and weighs an average weight of 50 kg.

Because of the widespread lack of nutrition of many of the customers interested in this product, the ease of operation was an important consideration. The easier the pumping action could be meant that the operator can use the product effectively for a longer period of time. The product's foot stroke length, which is the vertical distance the operators' feet move while pumping, was to be as short as possible while still delivering an optimal amount of water with each pump.

The optimal operator's foot stroke length was defined as being between 100-350mm. The larger stroke distance of each step could deliver more water per pump, but would require more energy. A smaller, less energy-required step would deliver an insufficient amount of water to keep crops irrigated. Between these two extremes, an

optimal stroke was to be determined to deliver an adequate amount of water while still allowing the operator to use the product for extended periods of time.

The ideal distance between the treadles' inner edges was determined to be 175-200mm apart. The spacing is to allow for the user's hips and feet to be in line with each other, thus delivering optimal power with each step. The ideal treadle width was determined to be 125-150 mm. Having wide treadles would allow for people of different hip-widths and foot-sizes to comfortably stand and use the pump.

Special thought was placed on the stature of the operator while using this pump. A comfortable upright position was determined to be the best for extended periods of operation. This is the human body's natural stance and reduces the strain on the operator's back by minimizing the time spend in a hunched position. This also places the operator in a stance in which they deliver all of their body weight and force in a downward motion, requiring less usage of their nutrition-depleted muscles.

### ***Safety Considerations***

Concerning the topic of safety there were two important factors to take into consideration. The first topic was the ergonomic factor, which would be a factor while somebody was operating the pump. By addressing ergonomic concerns, such as the stroke height and operator height, the treadle pump would become easier to use safely every time.

The second topic was the installation factor, which would be a factor when the operator was assembling the pump. Facilitating the safety during the installation of

the treadle pump was also determined to be an important consideration. The typical consumer would not have the technical knowledge to assemble a complicated product.

### ***Health Issues***

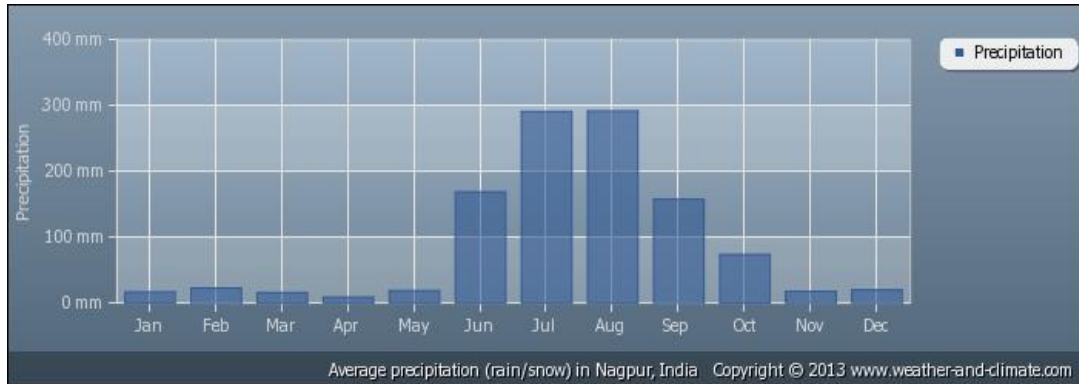
The health issues related to India were a key player in the consideration of the design and construction of the refined treadle pump. It has been estimated by the World Bank that India is ranked 2<sup>nd</sup> in the world for children suffering from malnutrition. This is second only to India's neighboring country of Bangladesh, who has an estimated 47% of children showing signs of malnutrition. The data on children's health is a small fraction of the story of India's problems with malnutrition and lack of basic wellbeing.

Multiple studies have produced beneficial data of the effects of a treadle pump on villages. Results from a study by The Energy Resources Institute (TERI) found that villages that had adopted the treadle pump showed an increase in cultivated acreage of up to 255%. With these larger crops, additional income was then able to flow into these farmers' families. This effect is made visible in a report by the Acumen Fund, which reported that 83% of families were able to add milk to their diets, as they were able to purchase the livestock required to produce these byproducts. These additional profits and micronutrients attained through the addition of a treadle pump show the effect treadle pumps can have on this region.

### ***Environmental Factors and Farming Methods***

The success of India's growing seasons is dependent on the rain patterns of the region. Without the aid of water pumps, many farmers are only able to successfully

grow crops during the monsoon season. The region's average rainfall can be illustrated by the city of Nagpur, India in Figure 6.



**Figure 6.** Average Yearly Precipitation in Nagpur, India

As shown by Figure 6, the majority of the rainfall for the year comes during the monsoon months of June through September. The rest of the year is relatively bleak concerning rainfall.

The only solution for obtaining water during the rest of the year is from underground wells or nearby rivers. This strenuous inefficient activity is limited by both the availability of water and the strength of the farmer and their ability to carry water long distances, through scorching temperatures, across uneven terrain. Figure 7 depicts a farmer watering his crops using this manual method. In this image, the farmer is most likely carrying approximately 80 lbs of water on his back.



**Figure 7.** Indian farmer utilizing alternative irrigation methods

Farmers in India also resort to the use of diesel pumps to irrigate their land during the dry seasons. Renting a diesel pump can cost a farmer 80 rupees per hour, which is the equivalent of \$1.49 US. With a daily income of only \$2, the cost of renting a diesel pump is an astronomical expense. If a farmer chooses to utilize a diesel pump, they will often use it to flood their fields in order to get the most use of it. Unfortunately, flooding their fields also washes away valuable topsoil, which is integral to the production of healthy crops.

India as a country sits relatively low compared to sea level. A majority of India's elevation is 2 m below sea level. This low elevation results in a relatively shallow water table. According to a video by IDEI or International Development Enterprises – India the average water table is a mere 2m below the surface of the land. With water levels so close to the surface the simplest solution to obtain water is the water pump. This is where the simplistic treadle pump design showcases its strengths.



## DESIGN SPECIFICATIONS

In order to ensure that the refined treadle pump design complied with the requests from ATC and that the changes made to the original design improved the value of the treadle pump, a list of weighted design specifications was produced. Ranking a list of twenty-six generic design specifications in order of importance, the top ten were weighted and then defined to fit the problem definition. The weighting of the specifications was done based on the nature of the requests from ATC, the anthropological and environmental research done on India, and on the basic benchmarking study. Conversations held with ATC advisors and other consultants were also used as a resource in the weighting of the design specifications. The top ten design specifications and their respective weights are shown in Table 2 below. Careful consideration of each of these design specifications was an integral part of successful design.

Table 2. Top 10 Design Specifications

<i>Top 10 Design Specifications</i>	
<i>Function &amp; Performance</i>	<i>10</i>
<i>Operating Instructions &amp; Ease of Assembly</i>	<i>9</i>
<i>Product Cost</i>	<i>9</i>
<i>Transportation and Packaging</i>	<i>9</i>
<i>Quality</i>	<i>9</i>
<i>Weight</i>	<i>8</i>
<i>Energy Consumption</i>	<i>7</i>
<i>Aesthetics</i>	<i>6</i>
<i>Mechanical Loading</i>	<i>6</i>
<i>Size</i>	<i>6</i>

### Function & Performance (10/10)

The purpose of a treadle pump is to free farmers from their dependence on rain fed irrigation and help farmers maximize return on small plots of land. The treadle pump can do most of the work of a motorized pump, but costs considerably less.

Pumps are normally described by their hydraulic performance, which indicates the discharge and pressure that can be expected for the effort put in. For treadle pumps, this is not an exact science because of the difficulty of standardizing the power input, which depends on the physical strength of operators and their ability to sustain this power over a period of time.

As an average measure, the suction head that is achievable by a treadle pump can be used as a performance indicator. A pressure treadle pump can lift five to seven cubic meters of water per hour from a water source with a suction head up to seven meters deep.

### Transportation and Packaging (9/10)

The intention of the current product is to be manufactured in a main city of a developing country using their limited available resources. There is also potential for small-scale workshops to manufacture multiple units at a time and distribute them to their immediate area. Both small scale and potential large scale manufacturing of this device require an ease of transportation and packaging for distribution. To accomplish this goal, the product should have the ability to be reduced from its constructed volume and be placed into manageable packaging. Overall product size will also determine how many units carriers could deliver on the ground in countries

like India or Guatemala. The shape of the product's box will allow for multiple units to be stacked on top of each other aiding in the delivery process.

With a majority of India's transportation comprising of bicycles and rickshaws, or small motorcycles, the overall shape and dimensions of the box will result in a manageable value for both customers and delivery services to move these units.

Packaging containing all required pieces for assembly will measure 32" x 12" x 6". These dimensions will allow 4 units to manageably be distributed to rural farmers and their crops using bicycles or rickshaws.

### Operating Instructions & Ease of Assembly (9/10)

The operating instructions and assembly instructions are important for a high-functioning user-friendly treadle pump. Because the finished ACT pump will be disseminated worldwide in the form of a construction manual, it is of utmost importance that the manual be flawless. This manual should describe exactly how the treadle pump should be operated and assembled with descriptive pictures.

The main concern about the instructions is to make them easy to understand. Because the target market is composed of people from different countries and different cultures, it is important that the manual be versatile. The finished product should be written at elementary school level with a picture or illustration accompanying every step.

### Product Cost (9/10)

The ideal cost of the final design will be less than \$100. It should be approximately 30% less than the price of other treadle pumps on the market, as many

of those prices include a 30% mark-up. This goal was given to the team in a conversation held with their ATC advisors.

### Quality (8/10)

The quality of the treadle pump design is two pronged: the first prong is quality from a manufacturing standpoint and the second is quality from a consumer's standpoint. Within the manufacturing facility the number of defects per thousand pumps made should be limited to less than one percent. That is less than one defect per thousand, which is the goal from a manufacturing standpoint. This one defect per thousand would be largely due to weld quality and experience of the plant personnel.

The second part of the quality design specification is the consumer's recognition of quality. The design should meet its service life of five years. If not, the manufacturer could be required to repair or replace the broken treadle pump as a guarantee to the customer that the product they are spending their valuable money on is worth the investment.

The quality after production is also of high importance because maintenance after purchase is rarely done. If a part of the treadle pump fails, the treadle pump is highly likely to be discarded and fall into disrepair.

### Weight (8/10)

The intention of a treadle pump is to be used as an irrigation tool in the open fields of our customers' farms. The average income of these customers is generally very small, about two dollars a day. Many will not have the means to purchase multiple treadle pumps to adequately irrigate their crops. With this being said, the weight of

these pumps must be manageable for any male or female to pick up and move this unit without the aid of others.

With the average adult male in India standing 5'5" and weighing an average of 60 kg, the weight of this product must not exceed 16kg to remain both useful to the user as well as competitive against the other treadle pumps in the market.

### Energy Consumption (7/10)

Operating a treadle pump, a typical person can burn 400-500 calories per hour. This is a considerable quantity considering that the treadle pump is designed for people that are often malnourished and have been working for the entire day on their farm. Changing the structure of the pump we hope to decrease the necessary effort to operate the pump by at least 50%.

### Aesthetics (6/10)

The original design lacks any aesthetically pleasing features. It has been expressed that farmers would appreciate a more stylish treadle pump that they could take pride in, something that should come with the investment in a treadle pump. The final design should look as though it is made to interface with the human body and could include other improvements such as paint and refined lines. The maximum budget assigned to improving the aesthetics of the treadle pump is \$5 and only if it is significantly more appealing than the aesthetics of competing treadle pumps.

### Mechanical Loading (6/10)

The treadle pump is powered by the means of the operator stepping repeatedly on the treadles. Because of this, the pump is put through the use of repeated mechanical loading. Therefore, the treadles themselves should be able to withstand

great amounts of force. The treadle pump should be able to withstand at least 500 lbs of force where the operator will be applying a force.

### Size (6/10)

The overall size of this product will allow for ease of shipping, storage, and mobility in the field. The unit will be kept as small as possible and will include space-saving removable features including, but not limited to, a removable handle used for operator stability. This feature will assist with product storage and shipping.

The base of the unit was to be reduced in size from its original design of 48" x 29" to a more manageable 30" x 15". Consideration was given to allowing the unit will have the option to interface with stakes that would be driven into the ground at each corner of the unit. These stakes would act as anchors to hold the unit stationary while in operation, giving the operator an adequate sense of stability and safety.

## **STUDY OF ATC'S ORIGINAL DESIGN**

In order to ensure that the refining process would be thorough, it was decided to construct the original ATC design based off of the manual made available on The Appropriate Technology Collaborative website. Through the construction process, it was hoped that the team would gain a multifaceted understanding of the task at hand. Additionally, the MSU team wanted to recreate the original pump so that it could be analyzed and its shortcomings would present themselves. Finally, the team was hoping to clearly identify where the starting point of the project was.

Upon completion of construction, several tests were performed to garner where the original ATC model stacked up against the market standard. Tests were also

executed to diagnose why the original model operated below the market standard. Finally, a list of shortcomings was compiled to use as a reference. This list was intended to highlight areas that could be improved upon.

*i. Construction*

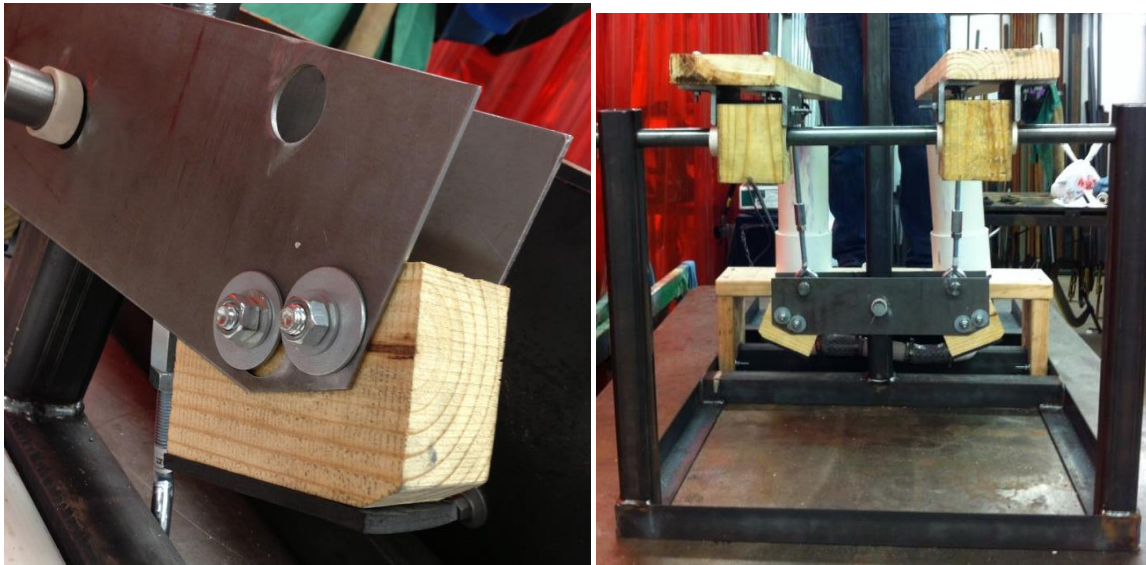
The construction process was carried out in the machine shop located in MSU's engineering building. Within the machine shop, the team had access to every common machining tool as well as a highly skilled staff of machine technicians who served as advisors. The construction process was thoroughly documented with pictures and notes on each step of the construction. This documentation later served as the means of determining a list of frailties of the original ATC design. The total man-hours invested in re-building the original pump was approximately 100 hours.



**Figure 8.** Frame of Original

The construction process began with the construction of the frame and the stability bar. These components were all made out of steel. The pump after these steps is shown in Figure 8 above.

Next the rocker arm and treadle components were assembled and added to the treadle frame. Figure 9 below shows two different angles of the rocker arm arrangement.



**Figure 9.** Left: Close up on rocker arm Right: Rocker arm with frame body

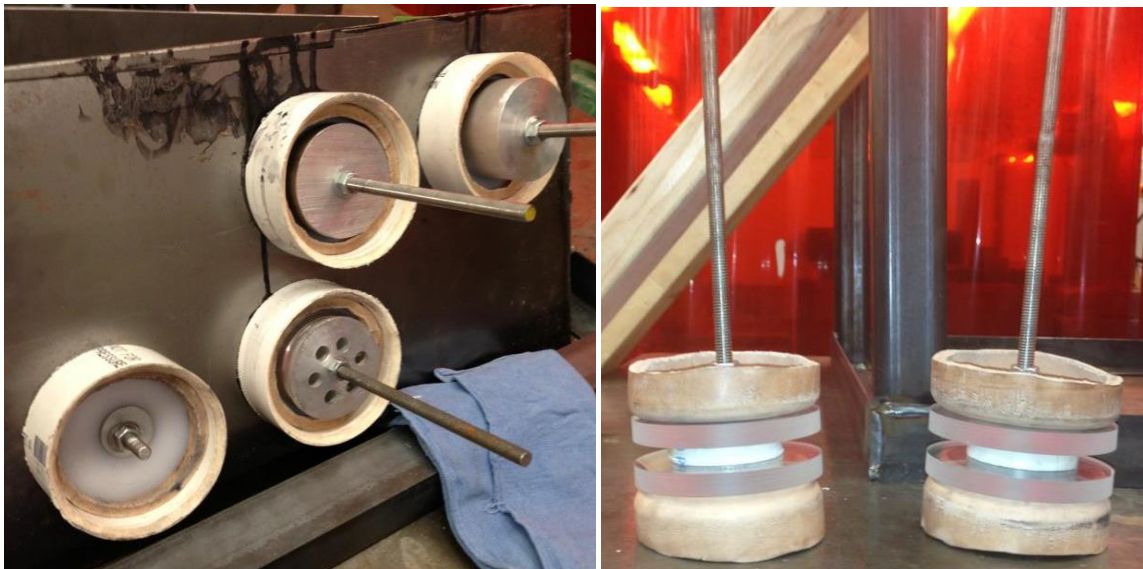
Once the construction of the frame and treadle portion of ATC's original design was completed, the team moved onto the construction of the pump component. The pump component consisted of a PVC pump housing, pistons, and piston seals. The pistons and piston seals were made concurrently with the cylinders. The components of the pump housing are shown in Figure 10. The image on the left shows the components before they were integrated into the pump while the image on the right shows how the pump housing components interfaced with the remainder of the pump.





**Figure 10. Left: Pump components Right: Components added to the design**

The most interesting part of manufacturing the piston assembly was the shaping process of the leather seals. The seals had to be soaked in water until they became flexible. After this they were forced into a mold, which made them adopt a cup shape. Figure 11 shows the shaping process of the leather seals and the completed piston assembly.



**Figure 11. Left: Shaping the leather seals Right: Completed piston assembly**

Once all of the components of the original ATC pump had been constructed, they were assembled to produce the finished assembly. Figure 12 shows the completed assembly of the original ATC treadle pump.



Figure 12. Completed assembly of original ATC design

### *ii. Analysis of Original Design*

Once the construction phase for the original pump was completed, a series of tests were performed to determine the level of performance that the original ATC could achieve. The results of these tests can be seen in Table 3. A test to determine the pump rate of the pump was run with water being drawn from the same height as the pump, which meant that there was no pump head. Under these conditions the original design was able to produce four gallons in a minute.

A second test was performed to determine how the pump operated for a variety of users. Two different team members were selected as operators. The first

operator was 6' tall and weighed approximately 230 lbs. The second operator had a frame more realistic to the size of the target market, standing 5' 7" tall and weighing 140 lbs. The first operator did not have a problem operating the pump, while the lighter operator had to occasionally jump on the treads to achieve motion. From this test, it was determined that the original ATC design had a static operating force of 140 lbs.

**Table 3.** Analysis of original ATC treadle pump

Analysis of ATC Design	
Water Displacement	4 gallons per minute
Treadle Operation Force	Dynamic: 45 lbs , Static: 140 lbs
Overall Pump Weight	110 lbs
ATC Pump Material Cost	\$401.78

Lastly, a cost analysis was performed on the finished pump. The cost analysis was performed based on material costs alone. In the actual production of the pump, labor costs could also be a factor. It is important to note that the calculated price could be slightly inflated due to the usage of US prices for the materials. It is believed that the materials would be available at a reduced cost in developing countries. To see an itemized cost report, refer to Appendix II.

### *iii. Areas for Improvement*

Throughout the construction of the original design, notes were assembled to create a comprehensive list of frailties found with the original ATC design. These listed items were used as a reminder in our final design to avoid repeating the same frailties.

The first area for improvement was found in the original instruction manual. The supplied manual contained errors and was unclear at times. One of the errors was

the lack of a comprehensive parts list located in one location. During the construction of the original design, components were missing from the instruction manual that resulted in a manufacturing bottleneck. Another error found in the manual was how instructions for specific components were vague and their plan of implementation wasn't always clear. This was specifically found when trying to plan the use of limited fasteners. Even with specified numbers of fasteners given in the original manual it was difficult to know when and where these varying length fasteners should be used.

Another area determined to contain a design frailty was the pump housing. The material selection for original ATC pump housing was PVC. This selection is not ideal considering the uniformity of large diameter PVC is weak. This unevenness in the surface finish resulted in the pistons frequently binding on the walls of the pistons. The PVC cylinders were also spaced roughly 14 inches apart. This resulted in increased product size and as well as an unstable frame construction.

The height that the original design located the operator off of the ground was approximately three feet. This was great cause for concern for the operator's comfort and safety. Another area that was a concern for the operator was the twisting motion created in the treadles due to extremely loose treadle pivots. The diameter of the pivots was loose with a 1" with a 2.5" interaction.

The material selected for the original design incorporated leather as a piston seal. During testing of the original design it was not uncommon for the pistons to bind inside their housing. These seals were also very difficult to effectively manufacture a uniform cup seal. The valves system on the original design comprised

of multiple PVC chambers that utilized thin sheets of rubber serving as flapper valves. These valves were not rigid enough to properly operate as a true check valves. This loss of efficiency meant the pump would not operate unless it was fully primed. The pump's loose seals also robbed the pump of creating any total system head, meaning the pump could not create a vacuum to draw water up any elevation.

The physical rod of the piston was constructed out of 3/8" threaded rod. The diameter of this rod was not large enough to handle the forces applied and often bent while under operation. Due to the poor interaction between the leather cup seals and the PVC pump housing of the original design the static operating force to begin operating this pump required 140 lbs of force with a dynamic force of 45 lbs to continue operation.

The frame that supported the original ATC design was constructed with large pieces of angle iron. These angle iron pieces were extremely heavy and made the overall footprint of the pump unmanageable for an operator of India's population to move or even lift. The original footprint of the angle iron pump frame was 48" x 29" with a total pump weight of 120 lbs.

Finally, the biggest frailty associated with the original design was the cost of raw materials required to manufacture this pump. The original pump's components if bought at box stores in the United States came to a price of \$401.78. This is well out of the market's average price of \$75.

## DESIGN CONSIDERATIONS

### *i. Project Scope*

Given the information gathered from benchmarking and research, conversations with ATC, discoveries made during the construction of the original pump design, and a limited project time, the scope was narrowed to cover the area deemed most pressing by the treadle pump team: improving the pump system to be more durable and efficient. The main components of interest within this scope were the seals, pistons, piston cylinders, and the valving system. These components were researched and various options for each were cross-referenced with the design specifications in a decision matrix to determine the best choice for each of these scopes.

### *ii. Design Considerations and Selections within the Scope*

#### Seals

A key component in the improvement of the pump system was the selection of the piston seals. Two of the most important decisions for the piston seals were material selection and seal-type selection. The original model implemented by ATC utilized  $\frac{1}{4}$ " thick leather to create a cup seal for the pistons. Each piston had two cup-seals facing to the outer edge. The piston seal set-up can be seen in the Figure 13 below.



**Figure 13.** Original ATC seal configuration

During the testing stage of the original design, many problems arose concerning the seals. It was difficult to locate the specified leather -- a half hour drive was eventually necessary to procure this. The forming of the leather was more difficult than anticipated and the forming apparatuses had to be reinforced to achieve the desired result. Finally, the operation of the seals proved to be faulty. The manual for the ATC design called for the seals to be shaped using PVC of the same diameter as the final pistons. Because of this, the pistons were nearly impossible to fit into the pump housings and the lack of leakage paths severely hindered their ease of operation. Some objectives for the new seal design were to eliminate the material selection of leather, improve manufacturability, use materials that are readily available and affordable in developing countries, and to produce a seal that would be effective and durable.

It was discovered that seal material selection would play a large role in the overall quality of the pump, especially the durability and performance. Materials under consideration were leather, hard rubber, rubber from a bike or truck tire tube, and flip flop rubber. Leather had several advantages as a seal material. Some of these were that it has a low coefficient of friction and that it will swell to fit any void with exposure to water. However, if a replacement was needed, the proper leather would be hard to find in developing countries. Tire tube and flip-flop rubbers both have the advantage of being readily available, making them very affordable in developing countries. Rubbers such as these were labeled as less desirable for use as a seal because they have a higher coefficient of friction.

Hard rubber has been observed in use as a seal for treadle pumps, such as the KickStart MoneyMaker, with high success. Hard rubber seals would most likely have to be formed in a manufacturing facility and included in the pump housing. The replacement of these seals may be difficult in rural areas, which is a factor that was brought into consideration.

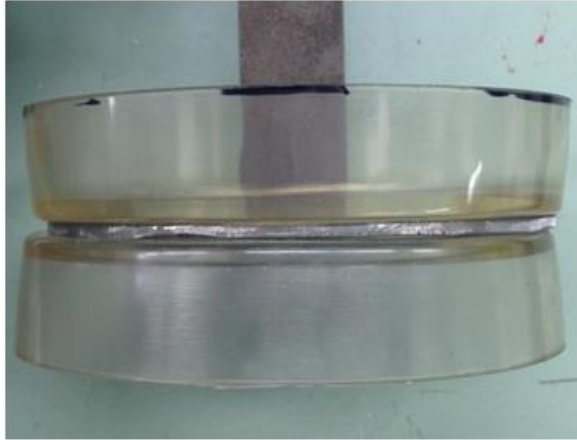
Seal types that were investigated were cup seals, labyrinth seals, u-seals, and flat “O” seals. Figure 14 displays these four seal types. Both U-seals and Labyrinth seals are advantageous when deviating from leather as the seal material because they do not rely on friction to create a seal. Labyrinth seals are comprised of a series of rings of varying diameters. The differences in the diameters create pressure drops, which prevent water flow. U-seals have a divot in one side, thus allowing for the seal to push outward and create a stronger seal when water attempts to flow in an undesired direction.





**Figure 14.** Seal Types. Top Row: flat “O” seal and labyrinth seal  
Bottom Row: cup seal and “U” Seal

It was ultimately decided to utilize a hard rubber seal in the cup shape. These seals would be injection molded at a nearby facility. From conversations with ATC and other consultants, injection molding is a process that is readily available in many developing countries. By producing the seals in this manner, it can be guaranteed that the seals will meet the standards required for proper pump operation. The model for the mold was included in the final construction manual for reference. Figure 15 displays the final seal configuration.



**Figure 15.** Final Seal Configuration

Due to concerns with friction between the seal and the piston cylinder, a 1 mm gap will be provided between the outside diameter of the seals and the piston cylinder. A small hole will be included in the piston configuration to allow water to come above the pistons and seal the gap.

### Pistons

The main concerns in the design of the pistons were durability, manufacturability, and creating a quality interface with the remainder of the pump.

The original ATC pump relied on 3/8" threaded rod as the piston shaft. These piston shafts deflected when force was applied and were not able to achieve the desired durability standards. The new piston shafts were chosen to be made out of .25"x1.25" bar stock. This decision was made because of material availability and because of increased durability.

Because the seals and pistons work as a unit to achieve a goal, the design of the two components was intertwined. A leakage path analysis was performed on the pump to determine the ideal size leakage hole to create the water seal around the piston. The hole had to be large enough to accommodate the flow of water while, but

it could not be too large as this would affect the pressure within the pump. Too large of a leakage hole would have caused the pressure within the piston to drop and would have compromised the pump's performance. The ideal size for the leakage hole was determined to be 3.5 mm. to meet a specific pressure head while sealing the pump and minimizing friction.

The final piston design can be seen in Figure 16.



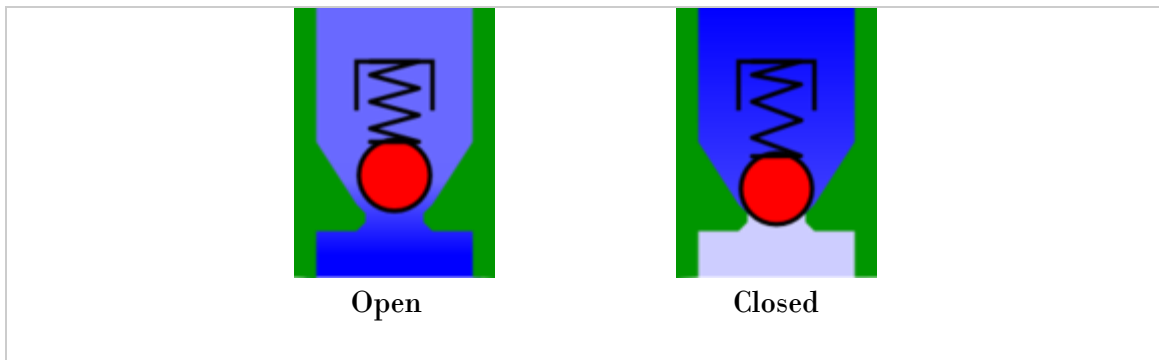
**Figure 16.** Final Piston design

### Valve Box

The valves were a strong focus for our final design, specifically to address the pump's efficiency. One of the frailties of the original ATC model was shown through the valve system used and its inability to provide a steady flow of water. The original ATC pump design was essentially working against itself. Water was lost into the water chamber during the one treadle's downward stroke. During the transition to the down stroke of the other treadle, the backflow of water out of the system allowed air to enter the water chamber. For the next downward thrust the chamber had to

again re-fill with water and push out air before the water could exit through the output.

This process was an extremely inefficient pumping method and provided a repeated pulse of water followed by a pulse of air. If the rural farmer was trying to consistently supply a large amount of water for irrigation, this would be extremely hard to maintain with the valves found on the original ATC model. The prevention of the back flow of water in the pump was the motivation for improving the valves on the ATC model.



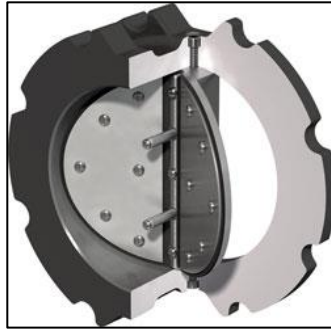
**Figure 17.** Backflow prevention concept using ball-check valve example

For the final design the team narrowed the options for valve choices down to three different options. The first of these was to maintain and improve the thin rubber valve on the original design that had been termed the flapper.



**Figure 18.** Flapper valve made of thin rubber

This was ruled out because of the variation of thickness and type of rubber that will be available depending on where it is manufactured. This valve system would take a lot of perfecting to get the placement of the thin rubber in the correct position to work properly.



**Figure 19.** Hinge valve

Hinge valves were the second choice for preventing back flow of water within the pump. However, a deeper investigation of hinge valves showed that they are not cost effective and contain a large number of working parts. Ultimately increasing the chances for part failure.



**Figure 20.** Exploded view of a homemade ball check valve

To make this pump cost effective as well as easy to manufacture and maintain, the team strongly considered utilizing ball-check valves. Ball-check valves can be manufactured using plumbing supplies and a marble or bouncy ball. Ball check valves are also available at a plumbing supply store pre-fabricated and ready to

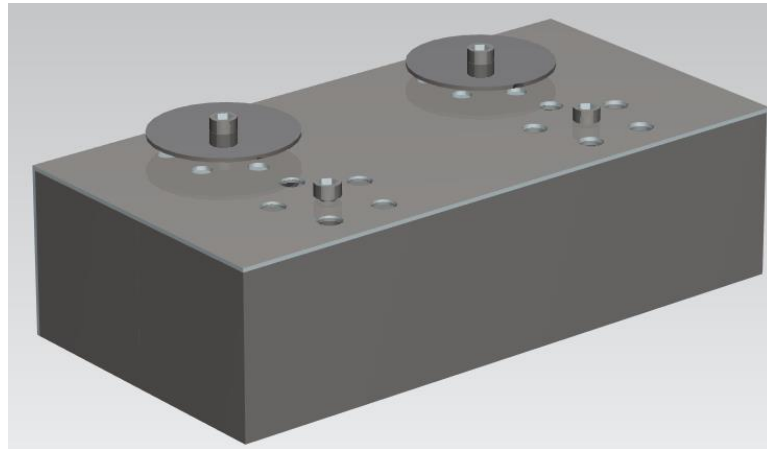
purchase. The ability of the ball check valve to prevent the back flow of water will greatly improve the pumps efficiency.

**Table 3.** Decision Matrix for Valves

<b>Valve Decision Criteria</b>	<b>Weights</b>	<b>Spring Loaded Valve Box</b>	<b>Ball check Valves</b>	<b>Flapper valves</b>	<b>Gate Valve</b>
<b>Function and Performance</b>	5	5	5	1	5
<b>Operating Instructions and Ease of Construction</b>	4	4	2	4	3
<b>Cost</b>	4	4	1	5	1
<b>Transportation</b>	4	4	2	5	1
<b>Quality</b>	3	4	4	1	4
<b>Weight</b>	3	4	2	5	2
<b>Energy Consumption</b>	2	5	5	1	4
<b>Aesthetics</b>	1	3	2	1	2
<b>Mechanical Loading</b>	1	5	3	1	4
<b>Size</b>	1	5	1	5	2
	<b>Raw Score</b>	<b>120</b>	<b>79</b>	<b>88</b>	<b>79</b>
	<b>Relative Rank</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>3</b>

The decision to use a spring loaded valve box was made based on an overwhelming score using the decision matrix in Table 3. This matrix used the top ten design specifications that were ranked in importance one through five. Then each of the different valve considerations was also ranked one through five. The weighting factors were multiplied by the corresponding scores given to the valve consideration and then summed in order to give a raw score which was used to create a relative rank. The spring loaded valve box scored fours and fives in almost every one of the top ten design specifications. Mainly a five in function and performance and a four in

ease of operation, and cost is what gave the valve box its high score. This is a highly functional valve concept that is affordable and easily to manufacture that is the three main reasons why it was considered the best option.



**Figure 21.** Final valve box design

An additional component of the valve box would include a filter placed at the inlet of the valve box. This filter would be simply constructed out of window screen and attached to the inside of the inlet to the valve box. The idea behind the inlet filter was to keep rocks and other small items from damaging the seals. Because typically no maintenance is done on these pumps, no replacement can be expected from the farmer. Once the seals are damaged the farmers would be highly unlikely replace them so it is important to prolong the service life of the pumps as long as possible. It would also be possible to attach a filter made of screen to the end of intake hose. This would serve as an extra line of defense in keeping potentially damaging foreign objects out of the valve box and seals.

An additional component that was included in the design of the valve box was an intake and outtake hose connection compatible with a common garden hose. The market's standard pump averages a 1.25" intake and a 1" outtake and usually

suggests reinforced hose for this application. Procuring this sized reinforced hose in the United States was extremely difficult and, more significantly, expensive. The treadle pump team felt that it was an unrealistic expectation to ask farmers in developing countries to procure this special hose. Designing the intake and outtake hoses to fit common garden hose was done so that farmers in developing countries could easily begin using the ATC treadle pump without any additional purchases or accommodations.

### Cylinders



**Figure 22.** Final cylinder design

The cylinder decision matrix was created using the same method as the valves. Referring to Table 4 it can be seen that cylinders made of sheet metal were the optimal choice. Ultimately, cylinders made out of sheet metal were chosen for their high scores in functionality, cost, and transportation. The machined pipe option would function better, but is extremely expensive and unrealistic. Most shops in



developing nations would not have the lathe required to machine this pipe or the tooling required to get an acceptable surface finish.

**Table 4. Decision Matrix for Valves**

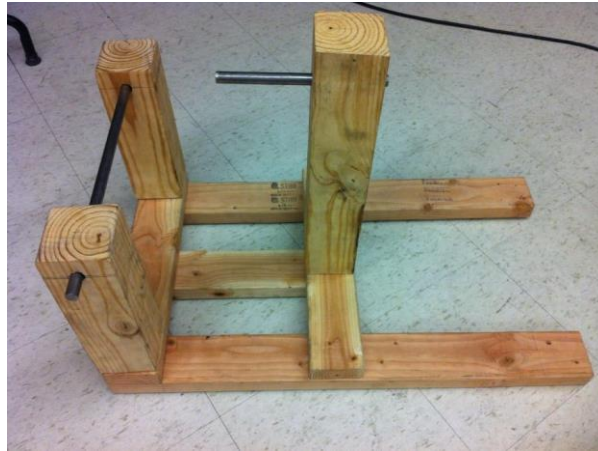
<b>Cylinder Decision Criteria</b>	<b>Weights</b>	<b>Sheet Metal</b>	<b>Machined Pipe</b>
<b>Function and Performance</b>	5	4	5
<b>Operating Instructions and Ease of Construction</b>	4	3	2
<b>Cost</b>	4	4	1
<b>Transportation</b>	4	4	3
<b>Quality</b>	3	3	4
<b>Weight</b>	3	4	2
<b>Energy Consumption</b>	2	3	3
<b>Aesthetics</b>	1	2	4
<b>Mechanical Loading</b>	1	2	4
<b>Size</b>	1	4	3
	<b>Raw Score</b>	<b>99</b>	<b>84</b>
	<b>Relative Rank</b>	<b>2</b>	<b>3</b>

### Suggested Frame Design

Although the redesign of the treadle frame fell outside of the project scope, some consideration was given to a treadle frame design. Upon the completion of the components within the project scope, it was determined that an operational treadle pump frame concept should be constructed to properly assess the accomplishments of the MSU team. Even though the frame was determined out of the group's project scope, effort was still put into improving this frame concept over the original frame design.

The frame design was constructed from readily available materials. These materials included stick construction consisting of 2x4, 4x4, square steel tubing, steel rod and basic hardware. The main function of this frame concept was to ensure that the pump housing, valve box, and pistons worked properly.

The base of the frame consisted of intersecting 2x4's that gave the pump frame appropriate strength compared to weight. The vertical portion of the frame was constructed using 4x4's and anchored from the bottom with lag bolts. The footprint of this assembly reduced the pumps overall size from 48"x29" to the current 32"x18".



**Figure 23.** Base of Frame Construction

As shown in figure 23 the rotational points on this frame were constructed from 5/8" steel rod stock. During testing, this rod showed that it was strong enough to handle operator weights upwards of 200 lbs without deflection.

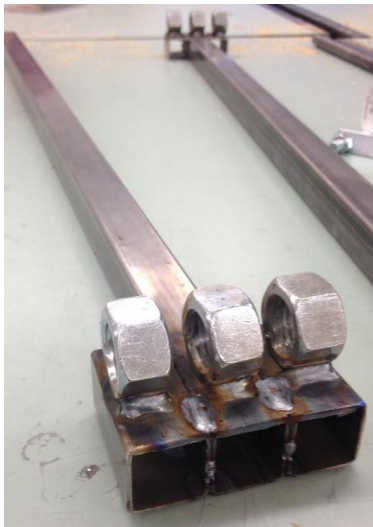
The rocker arm, shown in figure 24, was constructed using a 6" long 4x4 with symmetrical eyebolts and quick links used on both sides to interact with the pump's pistons. These bolts and quick links were available in multiple versions and sizes. The selected 3/8" components were rated to withstand 600 lbs. apiece. This resulted

in a product that was built with a factor of safety far exceeding any real-life forces that would be applied to this pump by an operator in the field.



**Figure 24.** Rocker Arm Assembly

The last component to be constructed was the treadles. 1x1" square steel tubing was selected for this application. The small size of this stock allowed for a seamless interaction between the treadles and the piston assembly. The pivot point of the treadles was widened with additional steel stock for added stability while under operation.



**Figure 25.** Treadle Rotation Assembly

Nuts were welded an equal distance to this widened portion of the treadle to act as the treadles rotational assembly. Further study will have to be done on the long-term effects of the nut's threads rotating about the uniform surface finish of the steel rod used for the treadle-to-frame mount. The upside of this assembly, currently shown in the short-term gains from using these nuts, is the simplistic assembly of common parts welded to steel stock. Additionally, the threads reduced the amount of interacting surface area, resulting in a large reduction of friction. This design should continue to operate correctly for years to come as long as the surface finish of the steel rod does not disintegrate with time.

Final construction of the treadles resulted in the addition of a six-inch drop for improved ergonomics, safety of operation, and aesthetics. This drop brought the operator lower to the ground, which gave them increased stability while operating the latest ATC concept. The addition of a 4x4 treadle stop was also implemented. This treadle stop, located at the rear of the frame, controlled the stroke length of the pump and helped to dissipate torsional forces on the rocker arm support and frame by planting these forces into the base of the frame that rests on the ground.



**Figure 26.** The original ATC design next to the latest concept pump and frame

By observing Figure 26 it is made obvious the improvement from the original design to the new concept. As was mentioned before, the overall size of the frame was reduced from 48"x29" to the current 32"x18". With the reduction in size accompanied with the replacement of steel with wood the overall weight of this unit was 60 lbs. This is a drastic reduction from the original model that weighed 110 lbs.

This frame concept is a reasonable frame for developing countries to construct as all of the components used were either wood or steel. The most difficult components to obtain would be the hardware associated with the rocker arm. These components could be swapped with basic chain and secured using large nails or bolts.

A section in the instruction manual was devoted to the recreation of this frame concept. The included dimensions of the manual allow others to create their own version of the frame using different building materials depending on availability.

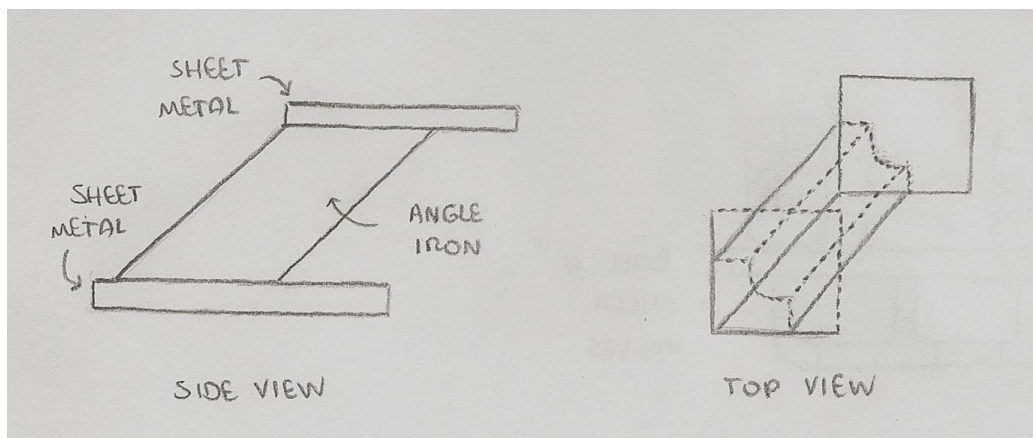
### *iii. Additional Considerations*

Through the gathering of information from meetings with ATC, weekly meetings with Dr. Thompson, and from discussion with classmates during in-class presentation several ideas outside of the project scope were developed. Due to limited time, the treadle pump team was not able to fully explore all avenues for innovation for the treadle pump, however some ideas were recognized as valuable. If time had allowed the team would have pursued these ideas more fully. We wished to document our thought process to benefit those who may wish to continue the process where the MSU team left off.

## Plumbing Supplies Pump

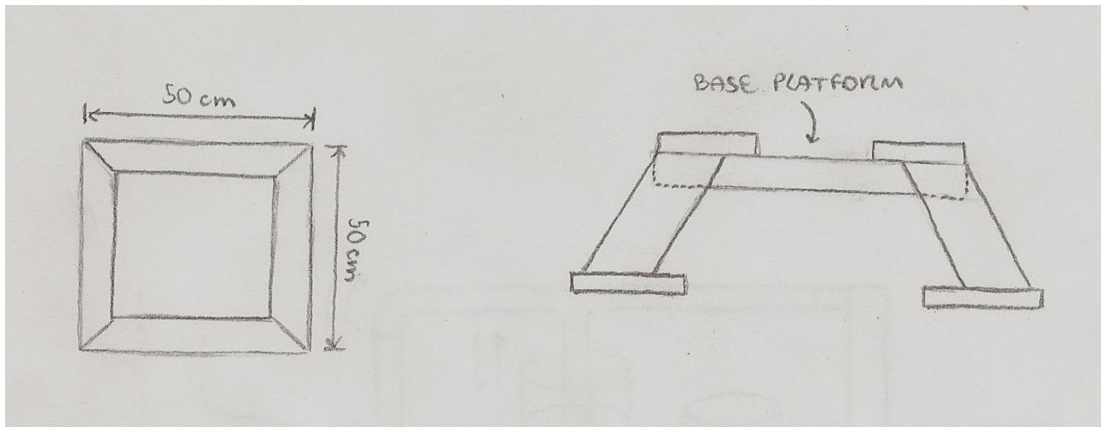
The inspiration for this design is to have a pump constructed out of a commonly available resource—plumbing supplies. These supplies are basic, readily available materials from capital cities of developing countries. These materials would comprise of angle iron, sheet metal, steel tubing, copper pipe, plumbing fittings, slip-on pipefittings (Speed-Rail), and a few other easily obtainable miscellaneous supplies. In addition, some materials such as used bike or automobile tires, paint, and plastic would be used to make the design functional, safer, and more ergonomically friendly.

The design would have a pyramidal-style base with four angle iron legs with dimensions of 5 cm x 0.5 cm x 25 cm, giving the height of 17.68 cm (about 7 inches) for the base platform. This height was chosen to put the user low to the ground while still allowing for hard plumbing of the pipes beneath the pump and the base platform. The legs would have 45 degree mitered ends on both sides so that 5 cm square sheet metal could be welded to each end of the legs. This would be used to attach them to the base platform and secure the treadle pump to the ground.



**Figure 27.** Pump legs with sheet metal for support

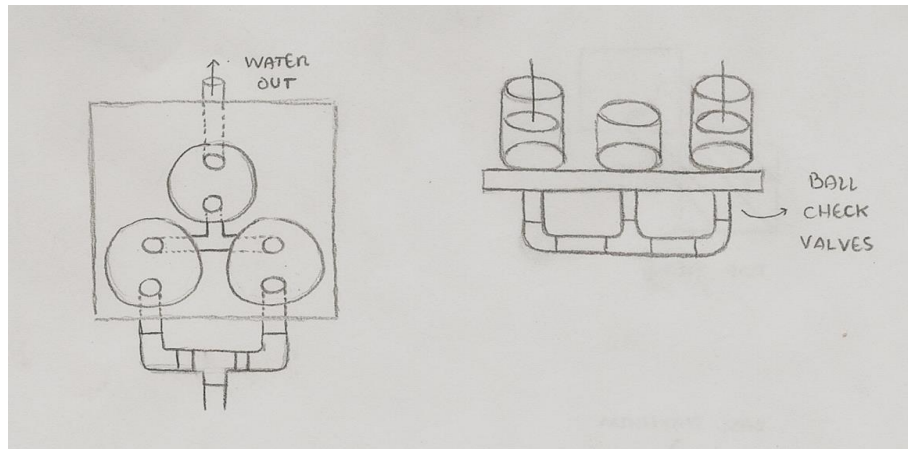
This base platform would be made of four 50 cm long angle iron pieces with the same width and thickness as the legs; these would also have mitered ends so that they could be welded together into an aesthetically pleasing 50 cm x 50 cm square. This angle iron square would later have a piece of 0.5 cm thick sheet metal attached to it to create a solid base platform to mount the piston-cylinder system.



**Figure 28.** Base Platform top and side view

This base platform and its legs were designed for the idea of a low-profile wide base that could give the user a stable feeling while the treadle pump is being used in a field or area where there may not have flat ground.

The next critical portion of the treadle pump is the pump and water chamber cylinders. This should be made out of steel tubing as it would provide the strength, durability, and the expected service life desired. The steel tubing should have a 15 cm diameter and be about 0.5 cm thick. The pump cylinders should have a height of 20 cm and the water chambers a height of 15 cm. These three steel tubes would be welded both inside and outside of the tube directly to the sheet metal to create a watertight seal.



**Figure 29.** Pump Layout with plumbing schematic

The plumbing for the pump would be hard plumbed. This means that there would be no hose except for where the water source attaches to the pump. It would be plumbed with copper pipe and fittings. Copper is a much softer metal than steel, which makes it easier to work with, but more durable than options such as PVC. Various lengths, widths and contours can be achieved more easily with copper than with steel. Copper pipe and fittings are also resistant to bacteria and rot, assuring a clean and safe water supply. Included in this hard plumbed pump system would be ball check valves. The check valves would use marbles or rubber balls (bouncy ball) to prevent the back flow of water for improved pump efficiency.

The next component, being the treadle pivots, would be attached to the frame using slip-on pipefittings and steel pipe, also commonly known as speed rail. Speed-rail is used in many applications for safety railing, but for this pump it would provide sturdy, lightweight, easy to assemble, construction of the treadle system. At the far side of the base platform away from the piston cylinders the speed-rail base fittings would be installed 40cm apart from each other. Coming out of the fittings would be two pieces of 30.5cm (1ft) steel pipe.





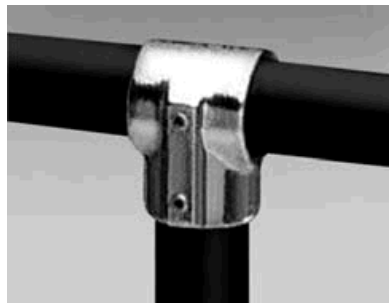
**Figure 30.** Speed-Rail Base Fitting

These two steel pipes would be connected together by two speed-rail 90-degree elbows and a 40cm piece of steel pipe.



**Figure 31.** Speed-Rail 90-degree Elbows

The treadles would be attached to this steel pipe using two more speed-rail pieces known as a tee, and two pieces of steel pipe 60 cm in length. These steel pipes would be positioned to hang over the position cylinders. This tee would allow for rotation necessary for the treadle action around the steel pipe but could be secured to prevent from translating left to right on the rail.



**Figure 32.** Speed-Rail Tee

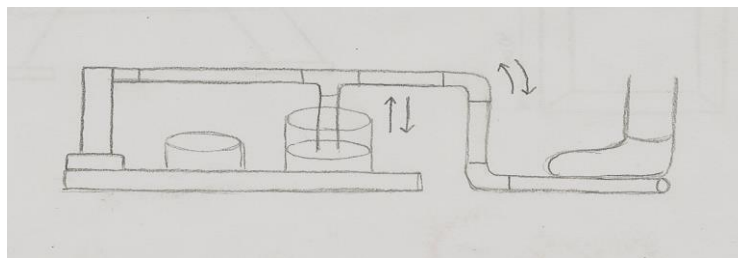
The piston assembly would be attached to the treadles using another piece of speed-rail known as a rotating tee. This would allow a steel pipe to drive the piston

and give the piston assembly the strength it requires, while still allowing the rotation necessary for the vertical motion of the treadles. The stroke in the piston assembly from top dead-center to bottom dead-center should be about 15 cm. This distance would give 5 cm of tolerance, stopping the piston from bottoming out while still keeping the piston from exiting the top of the cylinder while in use. The stroke would be controlled by a rocker-arm that would be attached to the steel piping and the base platform.



**Figure 33.** Speed-Rail Rotating Tee

At the end of each of the 60 cm long steel pipes would be another 90-degree tee that would lead another 20 cm pipe back towards the ground. At the bottom of those 20 cm pipes would be another set of 90-degree elbows that would have 45 cm long pipe leading away from the base platform.



**Figure 34.** Treadle system as seen from side

This design is intriguing and has the potential to work well, but it is a very expensive option for a base platform. Also, there are some questions about the availability of the brand name speed-rail in developing nations. If this particular

brand name pipe and fitting could not be found, basic plumbing supplies and set screws could be used to duplicate a similar frame.

### Bike Frame

This design concept was centered on the idea of transforming a bike into a treadle pump. With bicycles used as a primary means of transportation in India, the bicycle is an easily obtained raw building material. The premise of this concept is the use of a single bicycle's component's to build the treadle pump's frame and features. The bike would account for all pump components outside of the pump housing and pistons.



**Figure 35.** Basic, and non-basic, bike components

As shown in Figure 35, the bike components used to build the treadle pump are:

- Sprocket, Chain, Front Fork: Pulley Mechanism
- Rims: Treadle Pump Base

- Handle Bars and Top Tube: Used as a stability handle
- Front and Rear Hub: Treadle Pivots
- Rear Tube and Bottom Tube: Treadles
- Remainder of Frame: Structure

When trying to manufacture the entire frame and required components of a treadle pump from a single bicycle great care must be placed in the planning of where each component would be utilized.

Looking at the sprocket, chain, and front fork assembly the required interaction between the treadles could be created by using these components in a pulley system. This pulley system would serve to lift one treadle, creating suction in the corresponding cylinder, while pushing the other treadle downward, pushing water out of that cylinder and into the crops.

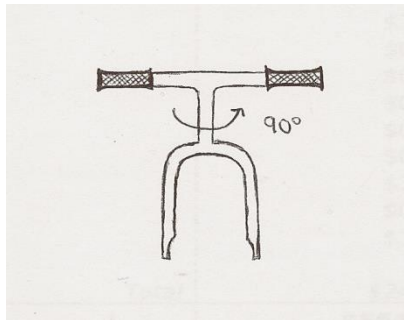


**Figure 36.** Fork and Stem separated along with Sprocket

To align the sprocket into the proper position to work with the treadles, the front fork must be rotated 90 degrees and retightened/welded once the proper position has been reached. The simplest means of creating additional chain tension could be created with a multi-speed bike's chain derailleur. A more involved, but secure, concept to ensure chain stability would be to create an assembly of gears that secure

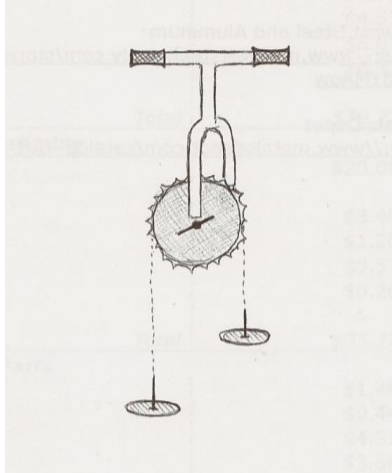
the chain both on the top and bottom of the chain, sandwiching the chain in the correct location.

During the monsoon season of India it would not be ideal to leave a chain exposed. Maintenance would be required to grease the chain on a regular basis. If the bike included a fender this fender could be used to shield the chain from rainfall, prolonging its life. A plus side to using a bicycle chain among other components of a bicycle is the relative ease of replacing these components, specifically the bicycle chain.



**Figure 37.** Stem and front fork before alterations

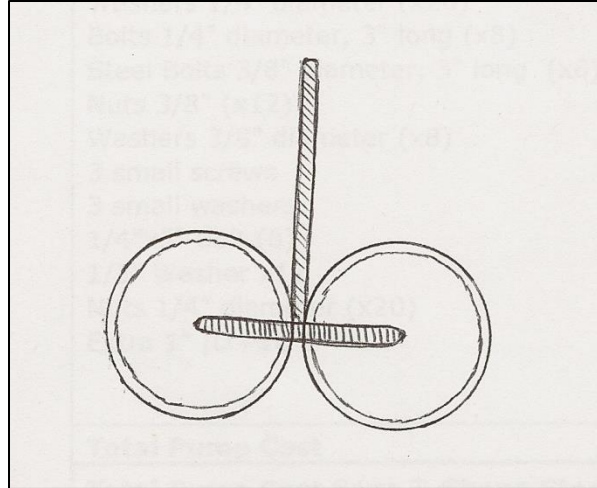
If the operator was interested in gaining additional height for the handlebars, the stem could be cut from both the handlebars and front fork. This stem would then be realigned, if a minor adjustment is needed, or fully replaced with steel from the top tube to gain a more ergonomic height for the user. This additional height would allow the operator to stand with a stronger, upright posture. This in turn would allow the operator to comfortably use the pump for longer periods of time.



**Figure 38.** Front fork with Stem, Sprocket and Chain to make the pulley.

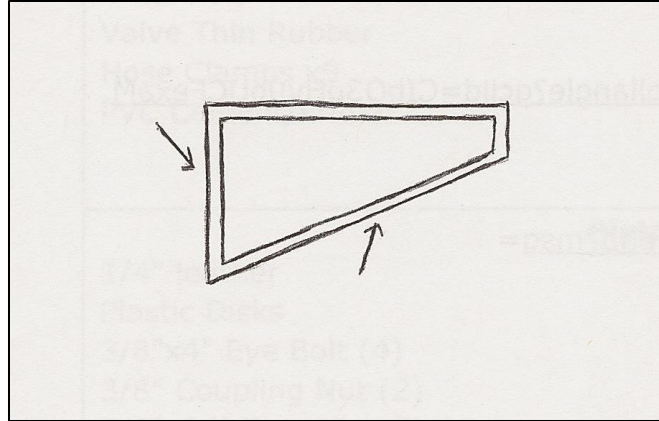
This treadle pump frame concept would only be desirable to a potential customer if they considered it to be a stable tool. Ultimately, this treadle pump would need to be safe not only for them, but also for their family to utilize on a daily basis.

The large rims found on a bicycle serve as an excellent means for the base of a treadle pump. These rims are relatively lightweight for their size. This allows for the treadle pump to maintain its mobility while gaining functionality. The open hoop design of the rims gives the pump a large amount of surface contact with the ground while still giving a majority of the unevenness of the ground the ability to pass through the interiors of the bike's rims. These rims would most likely be made of steel and could be securely welded together to obtain a very stable base. The remaining component would be a single bar from the rear fork of the bicycle. This piece of material would be used to help secure the rims together and give the pump housing a base to weld to. Finally, welded to this assembly would be the top tube that was welded to the rims, handlebars, and front fork.



**Figure 39.** Top view of the base

As represented by Figure 40, these two tubes from the bicycles frame would be used as the pump's treadles. Cut to be the same length, these metal bars would then be attached to their treadle pivots (the bicycles front and rear hub). For added operator footprint, the pedals would be welded to the sides of the treadles to increase the stability of this concept. These pedals would be fixed so that they would not rotate while being operated. If additional materials were required, a more user-friendly solution would exist in a board that would be clamped or bolted to these round tubes. This increase in ergonomics would add little additional cost and allow the operator to use this frame concept for extended periods of time.

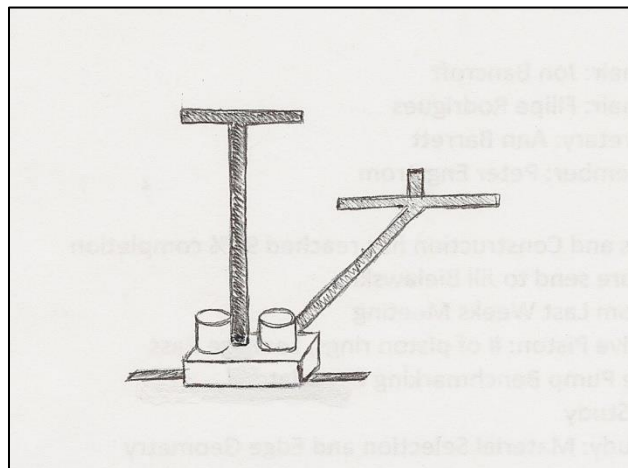


**Figure 40.** Central Frame

Additional materials from the bicycles frame would be utilized throughout the treadle pump frame for stability as well as features. With future groups potentially placing their scope on advancing this concept, a lot could be accomplished with someone's discarded bicycle.

### T-Shape Frame

After studying the possible combinations of frame shapes, treadle positioning and pump housing, the treadle pump team considered the implementation of the T-shape frame.



**Figure 41.** Central Frame

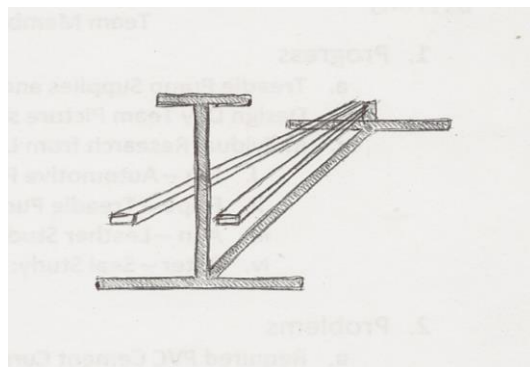


The frame utilizes a “T” shaped base, giving an optimal stability-versus-weight ratio. In the front the handle bar would welded securely onto the pump housing and “T” shaped base.

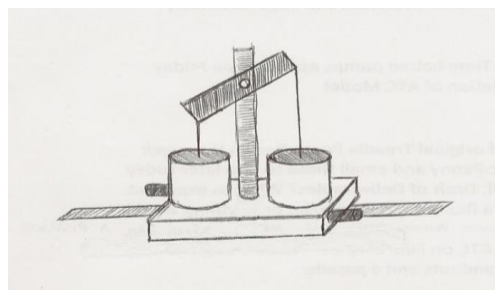
In this model the treadles are attached in the rear for greater mechanical advantage. This means that the operator would be able to create greater force at the pistons than with their own foot force at their location on the treadles.

A rocker arm would be used to guide the treadle movement, but the idea of use a bicycle gear should be taken into account as a possible driving system.

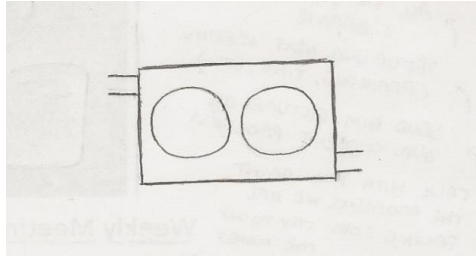
The pump housing would be made of steel. The use of hinge valves would be used inside the pump housing. Figures 42- 45 illustrate how the frame would be set up.



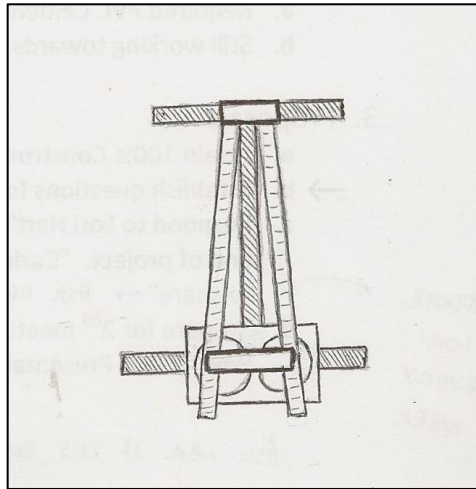
**Figure 42.** “T” frame with treadles



**Figure 43.** Pump housing with pistons



**Figure 44.** Pump housing top view



**Figure 45.** Treadle pump top view

### Recumbent Design

The irrigation of crops does not stop once a farmer reaches a certain age. With increased age, farmers could become too weak to adequately carry water or operate the treadle pumps currently available on the market.

A treadle pump design must be considered for a weak or even disabled market. This market may not possess the ability to stand for extended periods of time on the thin treadles that are seen on most treadle pumps found on the market today.

The answer lies in the recumbent design demonstrated by gym equipment in Figure 46, specifically bicycles and leg press machines. A design resembling this equipment would take the weight of the operator off the pump in a standing position and place them into a more ergonomically comfortable seated position.



**Figure 46.** Recumbent Gym Bike (Left) and Recumbent Leg Press (Right)

The key to this recumbent design is to allow the operator to sit and push outward with their back and lower body anchored against the seat. This supportive seat would effectively support their entire back while placing their legs in the appropriate position to efficiently and effectively operate the treadles of the pump for an extended period. Elimination of wasted energy associated with standing and transitioned into the operator's legs would allow the weak to maintain their previous lifestyle and aid in their independence from others.

Another aspect of the recumbent design is the increased leverage an operator can produce by anchoring their body and applying more leg force than their actual body weight would be able to produce in a standing fashion. With this increased force, a much larger pump head can be created. With this larger pump head a multitude of options are created. This could be region or job specific depending on the terrain or a possible holding tank that is greater than 7m in height. The increased force could also be used to force water longer horizontal distances as these distances are limited by the weight of water and the volume that is being pushed. With further study, the recumbent design could be a viable product for a specific market not yet designed for.

A concern with the recumbent design is whether the operators weight would actually be necessary, or at the least beneficial, to the smooth operation of the treadle pump. An investigation into the force easily produced by human legs versus the force of human weight would aid in discerning what approach is best.

### Flywheel

A flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia and thus resist changes in rotational speed.

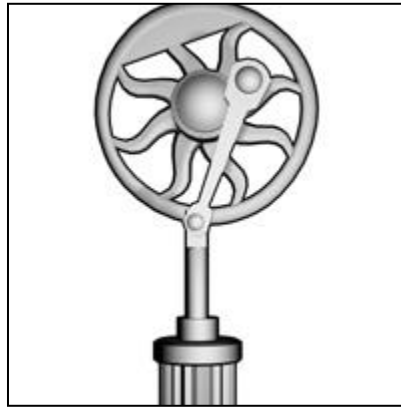


Figure 47. The flywheel could be used to move the pistons

The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby increasing its rotational speed, and hence its stored energy. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, in our case the pump pistons, thereby decreasing its rotational speed. Additionally, the flywheel is also proportional to the square of its radius. It would most likely require something the size of a car tire to create the rotational inertia necessary to pump water.

Additional force is required to first persuade a flywheel into movement from its resting position. However, once the wheel begins to rotate it would continue rotating much longer than a wheel without a flywheel. Flywheels can provide a system continuous energy when the energy source is discontinuous. They are also useful in delivering energy at rates often beyond the ability of a continuous energy source. This is achieved by collecting energy in the flywheel over time and then releasing the energy quickly at rates that exceed the abilities of the energy source.

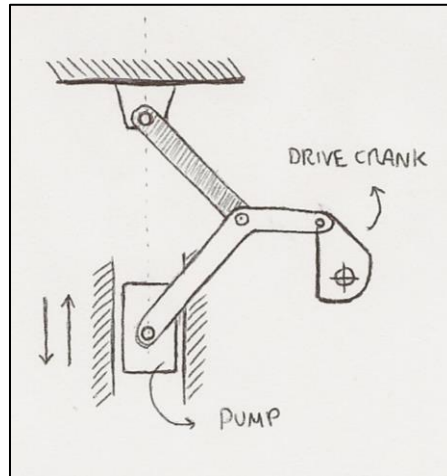
Flywheels can control the orientation of a mechanical system. In such applications the angular momentum of a flywheel is purposely transferred to a load when energy is transferred to or from the flywheel. The flywheel also lends itself to the option of a rotational input instead of the current linear input of the common treadle pump. A series of bike components could be implemented with this concept in order to achieve a significant mechanical advantage.



**Figure 48.** Example of flywheel/piston system

## Toggle Mechanism

Toggle mechanisms are four-bar linkages that are dimensioned so that they can fold and lock. The linkage is dimensioned so that it reaches a toggle position just before it folds. The high mechanical advantage allows the input crank to deform the linkage just enough push it beyond the toggle position. This locks the input in place.



**Figure 49.** Example of the toggle mechanism

This concept could be executed with a rotational input. As with the flywheel, an input different than the common “StairMaster” approach could be considered.

## Crank Mechanism

A *crank* is an arm attached at right angles to a rotating shaft by which reciprocating motion is imparted to, or received from, the shaft. It is used to convert circular motion into reciprocating motion, or vice-versa. The arm may be a bent portion of the shaft, or a separate arm attached to it. Attached to the end of the crank by a pivot is a rod, usually called a connecting rod. The end of the rod attached to the crank moves in a circular motion, while the other end is constrained to move in a linear sliding motion. As with the flywheel and toggle mechanism, the crank

mechanism allows for the consideration of rotational inputs as the driving force of the treadle pump.

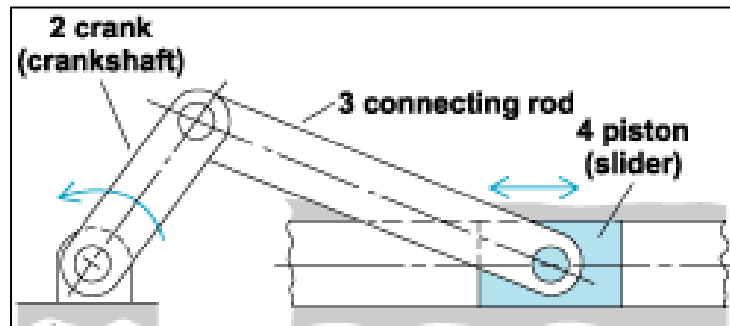


Figure 50. Horizontal crank mechanism, Treadle Pump would be in vertical orientation

## FINAL DESIGN



Figure 51. Finished re-designed ATC treadle pump

The finished prototype of the updated ACT treadle pump design can be seen in Figure 51 above. The prototype parts that fell within the project scope are painted orange. The basic design of the pump component is as follows:

The valve box and cylinders were constructed out of sheet metal and welded together to create a single pump housing piece. The cylinders will be bent and welded into place on the valve box. Within the valve box, an intake and an outtake chamber

was created. Water flow into the valve box, and subsequently in and out of the chambers is controlled by spring-loaded check valves. The inlet and outlet portions of the valve box are connection pieces to fit common garden hose in order to easily accommodate the hoses available to rural farmers.

The piston seals will be injection molded out of hard rubber. The selected seal configuration is a cup seal, with two outward facing seals per piston. The seals will be 1 mm smaller than the inner diameter of the piston cylinders to eliminate any friction concerns.

The pistons are constructed out of one-size of steel bar stock and the same sheet metal utilized in the construction of the valve box and cylinders. These components are welded together to create a permanent structure. To allow for a reliable seal in the piston cylinders, a small leakage hole has been added to the piston plate. A small rubber flapper on top of the hole prevents backflow during the valuable upstroke of the treadle.

### *i. Construction*

The construction phase of the final design was done keeping in mind that it had to be replicated in developing countries. Figure 52 shows the construction process of the final design. The valve box and pump housing construction is shown in the left column, the pistons and pistons plates' construction is shown in the center column, and the frame construction is in the right column.



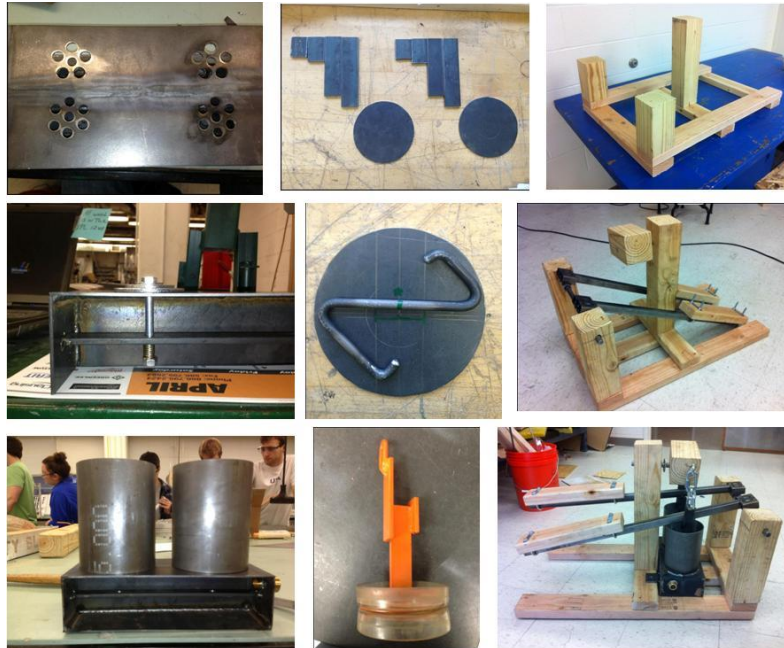


Figure 52. Construction process

During the construction, the team tried to use the same tools and processes people would have available to them in a developing country.

Because an instruction manual was being constructed concurrently with the construction of the final design, copious notes and pictures were taken during each step. To see the step by step instructions of the construction process, refer to the updated version of the construction manual.

## *ii. Fulfillment of Design Specifications*

### Function and Performance

The pump constructed for this project was subjected to testing that would simulate the most extreme operating height and hope to achieve a competitive output. Testing was done from the top of a bridge on Michigan State University's campus that sits nearly seven meters above the Red Cedar River. The pump operator was the team's smallest member who most closely resembled the build of a typical

person from the target market of India. This was an important control for the experiment because someone who is larger would have been able to pump water more easily and thus would have given unrealistic data that would not apply to the target market.



**Figure 53.** Red Cedar test setup

Testing was a success because the team was able to draw water from the depth of seven meters. At this height the pump managed to achieve an output of five gallons per minute or about half of what some ideal treadle pumps can produce. The reason why this pump did not move as much water as pumps already sold commercially could be due to the modification to the intake and outtake.

It was this realization that led the team to design a pump housing that could accommodate a standard five-eighths inch garden hose. Due to the intake and outtake sizes being cut in half it make sense that the output of the pump is about half of that of the market standard. In future designs if a higher output was desired, and the rural farmers had a means to acquire the larger diameter reinforced hose then changes could

be made to the pump housing to accommodate this, but for now it seems more cost effective for the poverty stricken farmers to use the pump as it was designed.

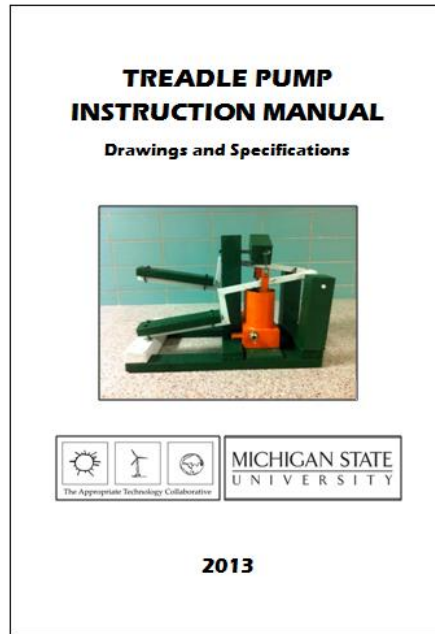
### Transportation and Packaging

The intention of the updated product is to be manufactured by small-scale workshops to manufacture multiple units at a time and distribute them to their immediate area. The finished design was created so that this design specification could be attainable.

The only limiting factor on the packaging for this product is the greatest dimension associated with it. The pump housing and valve box assembly would not require any kind of packaging as it is made of robust steel. If packaging was required for shipping the valve box and pump housing, it would measure no greater than 13” x 7” x 10”. Packaging containing the pump housing, valve box and current frame concept along with all other required pieces for assembly will measure no larger than 32” x 12” x 8”. Due to the weight of the new ATC concept pump of 60 lbs. it is reasonable that two units can be distributed at a time using bicycles with the proper rigging.

### Operating Instructions and Ease of Assembly

The final pump will be accompanied by an instruction manual, which describes exactly how it should be assembled with copious details and descriptive pictures. The main concern about the instructions was to make them easy to understand. Because the manual is for people from different countries and different cultures, the manual was written in a clear manner, with consideration of future translation to other languages.



**Figure 54.** Cover of New Instruction Manual

In the development of the final design, design for manufacture (DFM) techniques were used heavily. Where possible, material was used in repeated construction steps. For example, the sheet metal used to create the cylinders was also used in the creation of the valve box and the pistons.

### Product Cost

When analyzing the cost of the project scope it is helpful to compare it to the average market standard. The average treadle pumps cost around \$75 U.S. The focus of our pump without and frame or treadles came to \$47.35 U.S. The materials would cost a significant amount less in a developing nation such as India. Table 5 displays the cost analysis of the project scope alone.

**Table 5. Cost Analysis of Project Scope**

<b>Project Scope Only</b>			
<b>Item</b>	<b>Size</b>	<b>Quantity</b>	<b>Cost</b>
	Inches	feet / #	U.S. Dollars
Bar Stock	1.25x0.25	2.5	\$11.33
Sheet Metal	12x0.125	5	\$10.69
Round Stock	0.25	3	\$2.46
Eye Bolts	0.375	2	\$7.78
Galvanized Chain	0.375	0.5	\$3.06
Quick Links	0.375	2	\$4.78
Thin Rubber	4x4x0.125	1	\$1.09
Sholder Bolts	2.5x0.375	4	\$3.40
Nuts	0.375	4	\$0.36
Tension Springs	1.625x0.375	2	\$1.20
Tension Springs	1x0.375	2	\$1.20
Total			\$47.35

When the entire project, both the scope and the frame and treadles, was examined the price in U.S. dollars is \$99.04. Table 6 displays the cost analysis for the frame and treadles.

**Table 6. Cost Analysis of Frame and Treadles**

<b>Project Frame and Treadles</b>			
<b>Item</b>	<b>Size</b>	<b>Quantity</b>	<b>Cost</b>
	Inches	feet / #	U.S. Dollars
Square Tube	1x1	6	\$17.76
Nuts	0.5	6	\$1.50
Round Stock	0.375	3	\$2.46
U-bolt	0.375	4	\$3.52
Wood	4x4	4	\$7.71
Wood	2x4	6	\$6.80
Paint		3	\$11.94
Total			\$51.69

This is more than originally desired for a total pump cost, but it must be kept in perspective that in a foreign country the prices of building material would be considerably less. However, another aspect to consider with this cost analysis is that it doesn't include labor cost. All things considered with the decrease in cost of raw materials and the slight increase in cost associated with the cheap labor in developing

countries, the pump manufactured abroad would be comparable to the market average of \$75 U.S. dollars.

### Quality

Selecting materials that were durable and easily attainable ensured that a high quality final pump would be produced. Given the durable nature of the design, a service life of over five years is expected.

### Weight

The weight of this product, with the current frame concept, is 27kg. This weight was reduced from the original ATC design of 50kg, resulting in a weight improvement of 185%. Overall this weight reduction will increase the product's mobility and usefulness to the consumer. This reduction of weight also places the pump into a competitive position against other treadle pumps on the market whose average weight of 20kg is now much closer to the ATC model.

### Energy Consumption

With improvements made to the piston seal to pump housing interaction, increase in valve efficiency and increasing the ergonomics of the pump's treadles, the dynamic force required to operate the ATC pump was reduced from 45 lbs. to 10 lbs. while displacing water. This improvement in required operating force of 450% allows the operator to comfortably operate the new ATC concept for additional time while remaining comfortable and exerting less energy to obtain the same task. Increasing the water displacement of the ATC pump by 250% from 4 gallons per minute to 10 gallons per minutes results in less energy consumption as the task of irrigating crops is completed in less time with less energy exerted through higher efficiency pumping.

## Aesthetics

From our first meetings with ATC it was clear that farmers would appreciate a more stylish pump that they could take pride in.

Taking the concerns for aesthetics into consideration the final design was constructed in a smaller size, with a relatively sleek design. It was decided to paint the pump with colors that held some meaning for the Indian population.



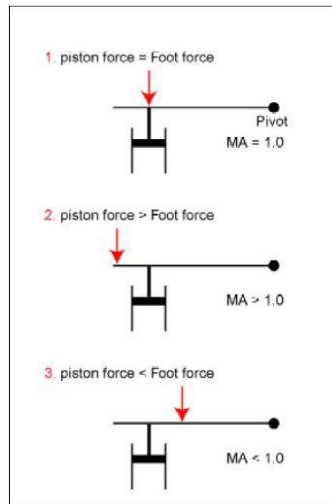
Figure 55. Indian Flag

The color scheme of the pump was inspired by the Indian flag. Doing this would facilitate the diffusion of our product. Each color in the Indian flag has a special meaning: the orange on the top represents courage and selflessness, the white in the middle represents peace and truth and the green in the bottom represents prosperity and fertility.

## Mechanical Loading

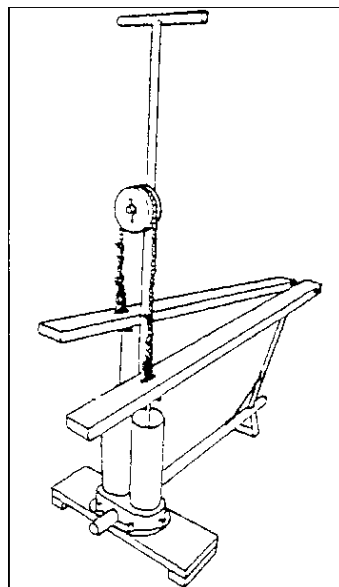
The treadle pump is operated through the use of its treadles. These treadles act as levers that rotate about a fulcrum. The force gained through the use of these levers or treadles can be calculated through mechanical advantage. As shown in

Figure 56 there are three types of mechanical advantage associated with treadle pumps.



**Figure 56.** Three possible Mechanical Advantage Scenarios

The ratio for mechanical advantage on a treadle pump is the distance from the fulcrum to the applied operator force over the distance from the fulcrum to the piston. The operator applying force directly above the pump's pistons obtains a mechanical advantage of 1.0.



**Figure 57.** Treadle Pump with a MA < 1



As shown in Figure 57, this style of treadle pump has a  $MA < 1$ . These pumps are often utilized for areas where extremely small pump heads are required. This is due to these pumps operating on nearly flat terrain and do not require the force associated with a large total system head. These pumps contain the largest piston stroke length resulting in larger pumping volumes being achieved with minimal movement.

The targeted pump design for the ATC pump concept is to give the operator ease of operation for extended periods of time while still having the ability to create a strong totally system head. The pump head of the original ATC design when tested was 0m and needed to be improved. Though increasing the piston to pump housing and valve assembly the new ATC design has a pump head close to the theoretical max for a treadle pump at 7m. The operation force was also reduced while increasing the pump head by selecting the second MA concept of placing the operators applied force further from the fulcrum than the piston force. This reduces the stroke height of the pistons reducing the volume of water that can be pumped per stroke but increases the force applied, hence the increase in pump head. The original ATC concept had a MA of 1.2 with a dynamic operational force of 45 lbs. The new ATC concept has a mechanical advantage of 3.25 with a dynamic operating force of 10 lbs. This is an improvement of 450% from the original design. This results in easier operation while increasing the pumps head and overall water displacement from 4 gallons per minute to 10 gallons per minute.

### Size

The base of the unit was reduced in size from the original design of 48” x 29” to a more manageable 32” x 18”. These new dimensions are for the frame concept constructed outside of the team’s scope. With further study additional improvements to weight and size reductions can be obtained.

### *iii. Analysis of Project Success*

Upon completion of the construction of the final design it was tested and compared to the original ATC model. The same tests that were performed for the original model were repeated for the new model. The most important parameters can be seen in Table 6.

**Table 6.** Final design performance

	<b>Original ATC Design</b>	<b>New Design</b>	<b>Percentage of Improvement</b>
Water Displacement	4 gallons/min	10 gallons/min	250%
Treadle Operation Force	45 lbs	10 lbs	450%
Overall Pump Weight	110 lbs	60 lbs	183%
Material Cost	\$401.78	\$99.04	406%

The table shows that our main improvement was in the operation force. The tests displayed a 450% of improvement in the operation force. Considering that the ergonomics of the pump was a primary concern of the treadle pump team, this achievement was regarded as one of the most notable.

Another great improvement was in the material cost to build the final design. The cost of the original ATC pump was \$401.78 and \$99.04 to build the updated

design. Since the product was to be used by farmers in developing countries that don't have a lot of financial resources the cost is a crucial concern.

## CONCLUSIONS

### *i. Impact of Project*

The impact that this refined treadle pump can have on India and the 80% of the world's population that lives in poverty is deeply moving. With the help of ATC, the expectation of this project is that this information will be disseminated to people who it can impact positively in rural India and around the world. It is known that the difference between a poor and rich farmer is access to water, this improved innovation grants access to water to the poor farmers of the world.

Great progress has been made to improve the original ATC treadle pump, however it should not stop here. There are numerous areas of improvement for the latest pump and it is the desire of the MSU team that other student or professional teams attempt to take on this project and further improve the design.

Together the top 20 percent of the world has a responsibility to the remaining population to continue to give the impoverished citizens of developing nations ways to have a sustainable life. With the help of the Appropriate Technology Collaborative and many other consultants this project was a powerful success.

### *ii. Future Considerations*

Even after establishing a final design for the semester, additional considerations for improvements were made. With more time or another semester

with this project a list has been established of possible improvements on the latest ATC treadle pump concept.

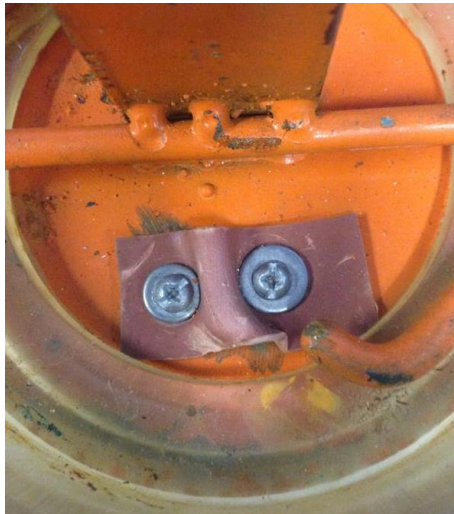
The first of these considerations is in the valve box. The pumps valve box vastly improved over the original design in both size reduction, improvement in quality and functionality. However, an area of concern is the welded shut manufacturing of the valve box. If a problem arose with the check valves there is currently not an access point to clear the springs of debris or replace any broken components. A future consideration would be to add an access door that is mounted on the face of each side of the valve box. This door would include a welded hinge with a latch and gasket to secure a watertight seal while still be able to obtain access to the innards of the valve box.

The second of these considerations is in the pistons of the pump. The pistons resulted in an easier to manufacture design that increased strength while reducing overall weight. There are only a couple places where the new piston design could be further improved with additional time. The first of these is the dimensions of the rods used to secure the seals in place. The overall sizes of these were reduced to increase the distance from the end of the rods to the sidewalls of the piston seals.



**Figure 58.** Piston Seal Rod to Seal Interaction

The idea of this improvement is to help the customer place new seals on the pistons with greater ease. However the play between the rod and the outer walls of the seals has resulted in the pump creating a squirting phenomenon. As pressure increases, water finds a way to deform the semi-solid seals, ultimately displacing the seals. This error is minor but still results in a loss of pump efficiency, total system head and creates a variable water path leakage.



**Figure 59.** Piston Directional Valve

Another area of improvement is the directional valve placed on top of the piston assembly. The original design and material selection for the directional valve is

not strong enough to keep the pressured water coming through the leakage hole from spraying out of the cylinder. A deflecting assembly was created to keep the spraying water inside the cylinder, however this no longer acts as a directional valve. Thus, water is then able to freely flow opposite of the intended direction through the leakage path hole. This loss of water above the pistons results in frequent pump priming, and a reduction of suction when operating the pump at large system heads.

A final consideration for improvement outside of the projects scope lies in the pump's frame concept. The reduction in size is noticeable with the latest frame concept as well as the 185% reduction of weight. The area of improvement lies in the wood construction of the frame not containing additional bracing for people of larger stature. This may or may not be of concern, as the pump's frame does not deflect under operation with people who are comparable with the Indian population average weight of 50 – 60 kg. If improvements were to be made to increase the frames rigidity additional cross bracing would be placed on the weight bearing 4x4's used in the construction of the frame. Additional strength can be added to the 1x1" hollow steel treadles by increasing them to 1x2" hollow steel treadles. The additional cross sectional area would increase treadle strength with larger loads.

These are considerations for future groups to start with when continuing the progress of the ATC treadle pump concept. With additional time and future generations of the pump being created an optimized version of each major pump component will result in a final product that competes among the best treadle pumps on the market today and into the future.

# APPENDIX

## I. Benchmarking Study

**Table 7. Summary of benchmarking activities**

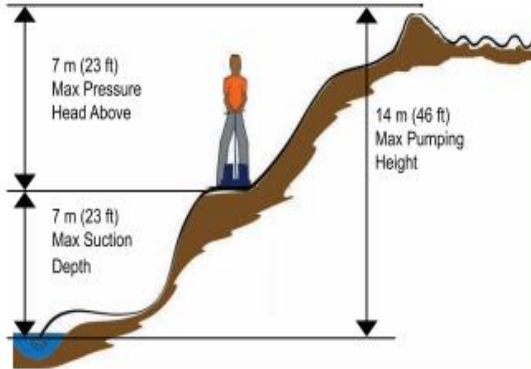
Brand name	Place of origin	Price	Flow rate L/hr	Max. Suction Depth	Max. Pumping Height	Push water distance	Weight	Basic material	Irrigation capacity
KickStart (MoneyMaker Max)	Kenya, Africa	\$150	5000-7000	7m	14m	200m	21kg	Metal	2 acres
Sunshine	Shandong, China	\$29-\$32	5000-9000				16kg	Metal	
Ajay	Uttar Pradesh, India		2000-24000					Metal	2 acres
Aov	Uttar Pradesh, India		5000-7000	7.5 m				Metal	
Jyoti Mechanical Movement	Uttar Pradesh, India		2000-2400	7m	16m			Metal	2 acres
Indocorp Afro Asian Consult.	New Delhi, India		5000-7000	5.7m				Metal	
KB (Surface Treadle Pump)			4500	8m			18kg	Metal	
KB (Bamboo treadle pump)			4500	8m			6kg	Bamboo	
Span Pumps	India		3000-5000	3m	3m		35kg	Metal	

# KickStart (MoneyMaker Max)

Place of origin: Kenya, Africa

Price: \$150

## Specifications



Specifications	Super MoneyMaker	MoneyMaker Hip Pump
Max. Suction Depth	7 m (23 ft)	7 m (23 ft)
Max. Pumping Height	14 m (46 ft)	14 m (46 ft)
Irrigation Capability/Day	2 acres	1 1/4 acres
Push Water Distance (flat ground)	200 m (656 ft)	200 m (656 ft)
# of Sprinklers Powered	5	3
Weight	21 kg	4.5 kg
Guarantee	1 Year	1 Year





# SUNSHINE

Place of origin: Shandong China (Mainland)

Price: \$29 - \$32

## Specifications:

- It is easy to transport
- Efficient, up to 5~9 cubic meter per hour
- Rustproof, long useful life
- 16.5 Kg/unit
  
- Material:metal
- Inner diameter:108mm
- Outer diameter:114mm
- Thickness:2mm
- Pump height:300mm
- Treadle:1000mm
- Frame:400mm
- Lift and pump head:1036mm
- Inner diameter of hose:48mm
- Outer diameter of hose:60mm



# AJAY

**Place of origin:** Uttar Pradesh India

**Price:** -----

## **Specifications:**

These types of Irrigation Water Pumps have discharge capacity of approximately 2000 to 2400 Liters per hour. They are suitable for irrigation up to the area of 2 Acres of land. Manufactured from the best quality raw materials like steel, our Irrigation Water Pumps are highly durable and long lasting in nature. In addition to this, we are considered as an eminent Irrigation Water Pumps Manufacturer and one of the top Exporters of the same.



# AOV

**Place of origin:** Uttar Pradesh, India

**Price:** -----

## Specifications:

- AOV Treadle Irrigation pump is a high Capacity pump designed to lift water by suction from shallow wells up to 7.5 Mts. And other surface sources.
- It has a capacity to discharge 5000-7000 liters per hour.
- It is operated by leg muscles in a comfortable walking motion and can be operated by one or two adults or two or more children.
- It is a double cylinder and double acting model, both downward stroke and upward stroke delivers water and optimum utilization of energy spent is achieved.
- A portable self-contained unit sits at ground level.
- Flexibility in installation, it can be moved from one location to another, without any permanent installation on a single well.
- Due to its simplicity and compactness, maintenance of the pump is economical in all aspects.



# Jyoti Mechanical Movement

**Place of origin:** Uttar Pradesh, India

**Price:** -----

## **Specifications:**

This unique pump is designed to displace water by suction from a depth of 7.5 meters. Our high capacity Treadle Irrigation Pumps can displace 5000 to 7000 liters per hour. Some other salient attributes of these pumps are: Portable Self-Contained Unit, Easy Manual Operation, High Capacity and Durable Life.

Steel Treadle Irrigation Pump (Pulley & Steel Rope Arrangement)
---

Suction Lift : 7 meter maximum.
---------------------------------

Delivery Head up to 16 meter.
-------------------------------

Discharge 2000 to 2400 Liters per hour.
---

Irrigable Area up to 2 acres of land.
---------------------------------------



# Indocorp Afro Asian Consultants

Place of origin: New Delhi, India

Price: -----

## Specifications:

For Irrigation, fully galvanized steel with dual 106.5 mm id-110mm, OD Cylinder, Nitrile Rubber Cup Washers, Valve Flaps, Gasket, Cast Iron Pulley, Handle, Rope for operation of Treadle, with wooden parts, suitable for discharge capacity of 5000 to 7000 liters per hour from a depth of 5.7 meter from ground level.



## Pressure Treadle Pump

The pressure treadle pump is modified version of the standard treadle pump. The Pressure treadle pump can be used to pump water from a source and lift and or transport water to a distant location.

### Main features

The pressure treadle pump has the following additional features in addition to main features of a treadle pump. It can lift water up to 20 m above ground level It can pump water up to 500 m from the source. Suitable for use with the sprinkle irrigation system



## KB (Surface Treadle Pump)

Place of origin:

Price: -----

Constructional Material	CRC (Cold Rolled Coil) sheet & mild steel
Pump Type	3.5 inch diameter (each) twin barrels
Maximum Stroke Length	100 mm
Weight	18 Kg
Operator's weight	Operates easily with 35-40 Kg operator's body Weight.
Maximum Suction Lift	8 meters
Delivery System	Open channel flow at atmospheric pressure.
Pedaling System	A pair of metal pedals integrated with counter weight, foot rest and bush bearing provides ease of operation & smooth pedals movement.
Stability	Tripod base is provided to have better stability & easy shifting.
Suction pipe size	1.5"(38 mm) diameter flexible PVC suction hose pipe. One end of the suction pipe is essentially to be submerged underwater.
Maximum Flow	4500 liters per hour
Water Quality	Resistant to silt particles but not suitable for saline water (EC>4dS/m).
Durability	8-10 Years

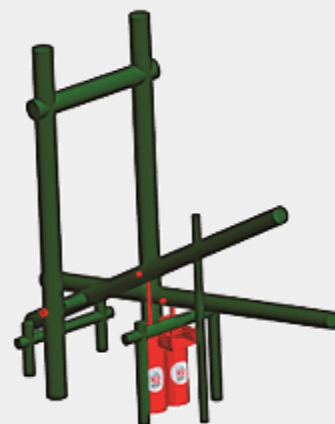


## KB Bamboo Treadle Pump

KB Bamboo Treadle Pump is a foot operated reciprocating type positive displacement pump to draw water with open channel water delivery system from shallow tube wells.

### Applications

- Small scale irrigation.
- Suitable for all type of crops (vegetables, cereals, cash crops, spices, medicinal, aromatic, flowers).
- Suitable for an area up to 0.4 ha (4000 sq m).
- Is ideal for regions rich in bamboo.



Constructional Material	CRC (Cold Rolled Coil) sheet & mild steel
Pump Type	3.5 inch diameter (each) twin barrels
Maximum Stroke Length	100 mm
Weight	6 Kg
Operator's weight	Operates easily with 35-40 Kg operator's body weight.
Maximum Suction Lift	8 meters
Delivery System	Open channel flow at atmospheric pressure.
Pedaling System	A pair of 6 ft long bamboo pedals used to leverage the pedal's up & down movement.
Bore Size	Suitable to install on 1.5" diameter bamboo/ plastic/ GI Tube well.
Maximum Flow	4500 liters per hour
Water Quality	Resistant to silt particles but not suitable for saline water (EC>4dS/m).
Durability	8-10 years



# Span pumps

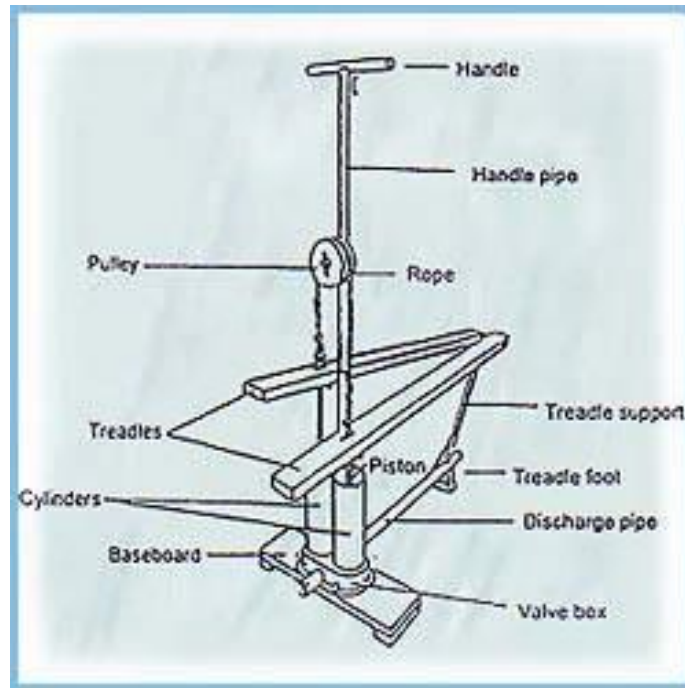
**Place of origin:** India

**Price:** -----

**Overseas:** Ethiopia, Tanzania, Zambia, Madagascar, Kenya, Nigeria, Sudan and South Sudan

## Specifications:

Construction	Modular
Pump body	Fabricated MS, galvanized corrosion resistant
Cylinder	Direct action reciprocating double cylinders
Ideal speed	As per human comfort
Out put	3000-5000 Liters per hour
Space requirement	1.5 sq m
Operating depth	3 m maximum
Operating Mechanism	Manually operated Pedal.
Lift	3 m above ground
Weight	35 kgs
Drop pipe	40mm x 3m, fitted with foot valve.



## See-Saw Pump



### Technical Details

Construction Details	Fabricated Mild steel
Wing span	3 m
Play mechanism	Seesaw
Capacity	8-16 children
Ideal speed	40 strokes per minute
Out put	1500-2000 Liters per hour
Space requirement	6m x 1.5 m minimum
Operating depth	Up to 80 m depth
Cylinder	Direct action reciprocating cylinder Of any deep well hand pump
Deliver head	8 m
Weight	600 kgs.
Riser pipes	As per user requirement

## II. Cost Calculation for Original ATC Design

<b>Frame Assembly</b>	
Steel Angle Bar 1/4" thick, 1 1/2" wide, 48" long (x2)	
Steel Angle Bar 1/4" thick, 1 1/2" wide, 28 1/2" long (x1)	\$28.31
Steel Angle Bar 1/4" thick, 1 1/2" wide, 2" long (x2)	
T-Shaped Bar 1/4" thick, 2" wide, 28 1/2" long (x1)	\$112.26
T-Shaped Bar 1/4" thick, 1 1/4" wide, 28 1/2" long (x1)	\$112.26
T-Shaped Bar 1/8" thick, 1 1/4" wide, 28 1/2" long (x1)	\$38.54
Steel Square Channel 1/4" thick, 2" wide, 23 1/2" long (x2)	\$60.48
Steel Square Channel 1/4" thick, 2" wide, 64" long (x1)	
Steel Pipe 1/4" thick, 1 1/4" diameter, 24" long (x1)	\$6.04
Sheet Metal 1/8" thick, 4 1/2" wide, 17" long (x2)	\$51.60
Sheet Metal 1/8" thick or less, 6.5" x42.5" (x1)	
PVC 1 1/4" ID, 4" long (x2)	
PVC 1 1/4" ID, 5" long (x2)	\$0.76
PVC 1 1/4" ID, 7" long (x1)	
<i>Total</i>	<i>\$434.87</i>
<b>Rocker-arm Assembly</b>	
1/2" Eye Bolt (4)	\$9.64
1/2"X12" Threaded Rod (2)	\$3.14
1/2" Coupling Nut (2)	\$2.62
Rubber 4 1/2"x3"x2" (x2)	\$43.62
Sheet Metal	See frame Assembly
Steel Rod 1" diameter, 12" long (x1)	\$8.00
PVC ID 1" 1/2" long (x2)	\$0.10
<i>Total</i>	<i>\$71.15</i>
<b>Treadle Assembly</b>	
2x6-92" Stud	\$4.16
Block of Wood 4"x4"x4"(X2)	\$7.77
Steel Angle Bar 1/4" thick, 1 1/4" wide, 6" long (x4)	\$6.32
<i>Total</i>	<i>\$19.35</i>
<b>Pump Assembly</b>	
4" DWV Coupling x2	\$4.22
Hosing 2 ft	\$8.10
1" Tee	\$0.86
4" Cleanout Plug	\$2.83
4" Cleanout Adapter	\$7.15
4" Cap X3	\$23.13
1" PVC elbow x7	\$3.99
4"x2' PVC	\$6.78
Valve Thin Rubber	\$4.57
Hose Clamps x9	\$6.61
PVC Cement/Primer	\$6.97
<i>Total</i>	<i>\$79.72</i>

<b>Piston Assembly</b>	
1/4" leather	\$20.00
Plastic Disks	
3/8"x4" Eye Bolt (4)	\$3.40
3/8" Coupling Nut (2)	\$1.20
3/8"x36" Threaded Rod	\$8.57
2"x2' PVC	\$0.20
<i>Total</i>	<b>\$35.37</b>
<b>Misc. Parts</b>	
Bolts 1/4" diameter, 1" long (x4)	\$1.49
Washers 1/4" diameter (x20)	\$0.44
Bolts 1/4" diameter, 3" long (x8)	\$4.31
Steel Bolts 3/8" diameter, 3" long (x6)	\$3.66
Nuts 3/8" (x12)	\$0.22
Washers 3/8" diameter (x8)	\$0.35
3 small screws	\$0.13
3 small washers	\$0.13
1/4"x5" Bolt (8)	\$6.96
1/2" Washer x12	\$3.96
Nuts 1/4" diameter (x20)	\$0.36
Extra 1" ID PVC 1'	\$1.00
<i>Total</i>	<b>\$24.39</b>
<b>Total Pump Cost</b>	<b>\$664.84</b>
<b>Total Pump Cost Sans T-Shape Steel Cost</b>	<b>\$401.78</b>

### III. Sample Calculations

Volume of a single full cylinder:  $V = \text{Cylinder Surface Area} * \text{Stroke Length}$

$$V = \pi * 60.75\text{mm}^2 * 92.075\text{mm} = 0.0012\text{m}^3$$

Mass of a water in a full cylinder:  $M = \text{Volume} * \text{Density}$

$$M = 0.0012\text{m}^3 * 1000 \frac{\text{Kg}}{\text{m}^3} = 1.2\text{Kg}$$

Force of water due to gravity alone=  $F_w = \text{Mass of water} * \text{acceleration due to gravity}$

$$F_w = 1.2\text{Kg} * 9.81 \frac{\text{m}}{\text{s}^2} = 11.77\text{N}$$

Force of spring in valve  $F_s = \text{Spring Constant} * \text{Distance Displaced}$

$$F_s = 2.7 \frac{\text{lb}_f}{\text{in.}} * 0.5\text{in.} = 1.35\text{lb}_f \approx 6\text{N}$$

These sample calculations show that since the force due to gravity alone on the volume of water in a full cylinder is almost twice that of the force of the spring, the directional valves should easily open with any additional downward pressure and likewise they will close with any additional upward pressure, such as the pressure created by the piston and seals in the cylinders.

#### IV. Additional Resources on the ATC Treadle Pump

##### **Pictures throughout the Semester**

[http://s1334.photobucket.com/user/ME478\\_MSU\\_2013/profile/](http://s1334.photobucket.com/user/ME478_MSU_2013/profile/)

##### **Videos of Testing Procedures**

ATC Treadle Pump Demo (Ann)

<https://www.youtube.com/watch?v=KWimQ9Qik3I>

ATC Treadle Pump Demo 2

<https://www.youtube.com/watch?v=6VOWybDA1EM>

ME478TreadlePumpTeam

<https://www.youtube.com/watch?v=Fd9APe0RZQk>

## V. References Used

- Rogers, Everett M. (1995). *Diffusion of Innovations* (fifth edition). New York: Free Press
- <http://www.ideorg.org/ourtechnologies/treadlepump.aspx> (visited 10, March, 2013)
- <http://www.fao.org/docrep/005/X8293E/X8293E00.HTM> (visited 10, March, 2013)
- <http://www.skipumps.com/malawipump.htm> (visited 10, March, 2013)
- <http://www.kickstart.org/products/super-moneymaker/> (visited 15, March, 2013)
- <http://auto.howstuffworks.com/clutch1.htm> (visited 15, March, 2013)
- <http://www.technologystudent.com/cams/link1.htm> (visited 15, March, 2013)
- [http://www.ehow.com/how-does\\_5159371\\_do-check-valves-work.html](http://www.ehow.com/how-does_5159371_do-check-valves-work.html) (visited 16, March, 2013)