Senior Project:

Final Report

Integrated Pump Design

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Abstract

The motivation for this project came out of the desire of garden workers in Mahadaga, Burkina Faso, Africa, to be able to pump water from the ground directly into barrel stands for irrigation. Currently, two pumps are necessary to complete the task of lifting water to the barrel stands. The Integrated Pump Design team's goals were to improve overall pump efficiency, satisfy the desire of the end user to integrate two existing pumps, and utilize culturally appropriate materials.

In order to improve the efficiency, head loss tests were done on several new check valve designs. These showed significant improvements over the original design during initial in house testing. Upon prototype installation, almost all of the new designs were ruled out due to the flap being easily pushed into the holes—allowing water to leak through. The original check valve design seems to be the best for the piston valve while the larger six - 1/2 inch hole design is an improvement for the foot valve.

The new pump design eliminates the existing single-piston pump by installing a seal around the piston rod at the top of the pump's riser pipe. This seal holds pumped water in the above ground portion of the pump while allowing the piston to still function. This maintains the simplicity and ease of use of the existing rower pump, while pumping the water directly into the barrel stands for irrigation. The need for a second pump, which is currently necessary with the rower pump, has been eliminated.

The objectives for this project were met with the exception of improving the output flow rate to 9 gal/min and sustaining it for 10 minutes. Due to the increased head, more input force is required to actuate the pump. Therefore the user becomes fatigued more quickly than with the previous rower pump (less head). Also, our original choice of 9 gal/min came from past experience, but we neglected to account for the motion that was being used. This flow rate was attained by a significantly larger stroke length (greater than 20 inches) and stroke rates faster than what we were testing. With the stroke lengths and stroke rates that we were measuring, 9 gal/min is impossible. We found that a better measure of the quality of our pump was a comparison of the outputted volume as compared to the volume displaced in the pump (See Figure 9).

1 Introduction

Since 1998, students of Messiah College have been doing work in Burkina Faso, Africa. In the small town of Mahadaga, photovoltaic-powered pumps and a lighting system as well as hand-powered pumps and an irrigation system have been installed at a clinic that reaches

Figure 1 - Current Mahadaga two pump system

out to handicapped and underprivileged people of the area. During the summer of 2000, two types of pumps were installed in 20 foot wells to provide more efficient access to ground water for irrigation purposes.

The rower pump is a displacement pump that lifts water to the surface by means of a lever arm actuation system. Once the water is deposited into a 55-gallon drum partially sunk in the ground, it can then be pumped via a hand-powered single-piston pump an additional 8-10 feet into barrels for storage (See Figure 1). The barrels are elevated to provide a pressure head to feed the irrigation system.

This past summer (2001), a team went to assess the wear, needed maintenance, and the nationals' opinions on the pumps after a year of use. The main thing that the national workers did not like was that they had to pump twice to get the water into the barrel stands. They wanted to be able to, in one pumping motion, move the water from the bottom of the well into the storage barrels. When a crude prototype of our project was constructed for them, they were very enthusiastic about installing it in the other wells to replace the old system.

The overall objectives for our project are to construct a pump that moves water from the ground into the storage barrels with minimal leakage and maximum efficiency.

1.1 Description

Two things are necessary for the successful completion of our project: (1) creating a seal that will allow water to be pumped an additional 10+ feet above the actuation point and (2) having a force input equivalent to the theoretical force necessary to lift an additional 10+ feet of water (i.e., no unnecessary frictional force additions).

Because of the current location of the actuation point—where the pump's piston rod exits the riser pipe—a seal needs to be in place before the piston rod exits the riser pipe. As the water rises above this point in the pump, a constant head will be placed on a seal. This head, or pressure, will need to be supported so that the water does not leak out of the pump. Our goal was that no water would be lost during pumping due to water head.

The greatest concern that we had before testing was that the pumping motion would disturb the seal. The actuation system can cause the piston rod to have a horizontal displacement of approximately 1 inch in opposite directions at the top of the riser pipe. Continuous pumping could result in the loss of significant water while pumping, undermining the efforts of the garden workers.

The seal's friction also came into consideration. In order to maintain a seal around the piston rod, the seal would have to ride against the surface of the rod or move with the rod. Two designs were considered for complexity and friction (the tighter or more contact area, the greater the friction). Different seal sizes were also tested to determine the best leakage to friction ratio.

In addition to looking at the seal, we decided to consider the check valves' efficiency. The head loss from these components, if minimized, could result in a lower overall pumping force as compared to the original rower pump with a 10 foot extension.

Our analysis for the check valves centered on the hole design and the best way to mount its seal. Four designs were tested: the current six - 3/8 inch hole design, a larger six - ½ inch hole design, a half-moon design, and a quarter-moon design. Each of these were installed in a test apparatus (See Appendix) and head losses were measured for various flow rates (with a focus around 18 gal/min).

1.2 Literature Review

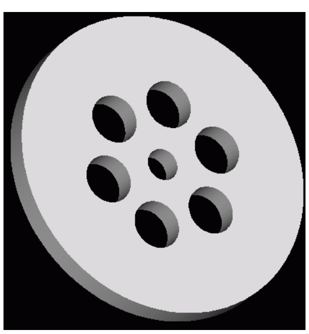
Among the positive displacement pumps in the world today, ours is very unique. It does use the standard checking system of a foot valve and a piston valve. It is also pumps via the piston rod which exits the riser pipe at the top. Our pump is distinct at the output. Instead of just emptying into a barrel, an additional length of pipe is attached to direct the water upward into storage barrels. The use of the seal on the piston rod makes this possible.

The literature review did not provide a significant amount of helpful information in our efforts to attain additional information for the design of our pump. Due to the work that the West Africa Project has put into the pump in the past and our activity with the pump's installment and upkeep, much of the design information necessary came from experience. The hand pump designed by a collaboration between IDRC (International Development Research Centre) and the University of Waterloo in Ontario, Canada, has been the main outside contributor to our pump knowledge. The use of a wooden center that was tried in Sri Lanka's check valve was ruled out due to its possible rotting and the need to be replaced sooner than a PVC disc. Our check valve design is also different than the Waterloo pump (i.e., not as long). Also, allowing the entire valve flap to raise and lower as one stiff piece was not pursued due to its complexity. And at this point, we have not seen it necessary to chamfer the edges of the check valve holes. Our commitment to keeping the design simple as well as effective did not allow for complicated additions.

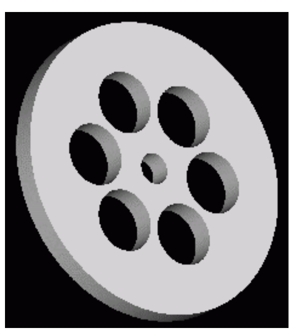
(Please see the Literature Review information gathered in the Dokimoi Ergatai archives.)

1.3 Solution

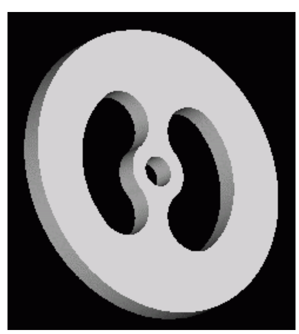
Our proposed design was accomplished with the old check valve design and a stationary seal with two rubber discs.



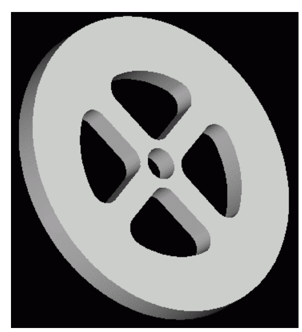
6 - 3/8" Holes



6 - ½" Holes



Half-moons



Quarter-moons

Through tests on the check valve, the original 3/8 inch hole design was determined to be the best for the piston valve, while the ½ inch or the 3/8 inch 6-hole design would be best for the foot valve. Too many problems due to the increased size of the holes and the increased head ruled out the half- and quarter-moon designs. The rubber flap was pushed into the holes causing major leaks in the pump. Contributing to this problem is the use of bicycle rubber for the flap. Because of our desire to maximize

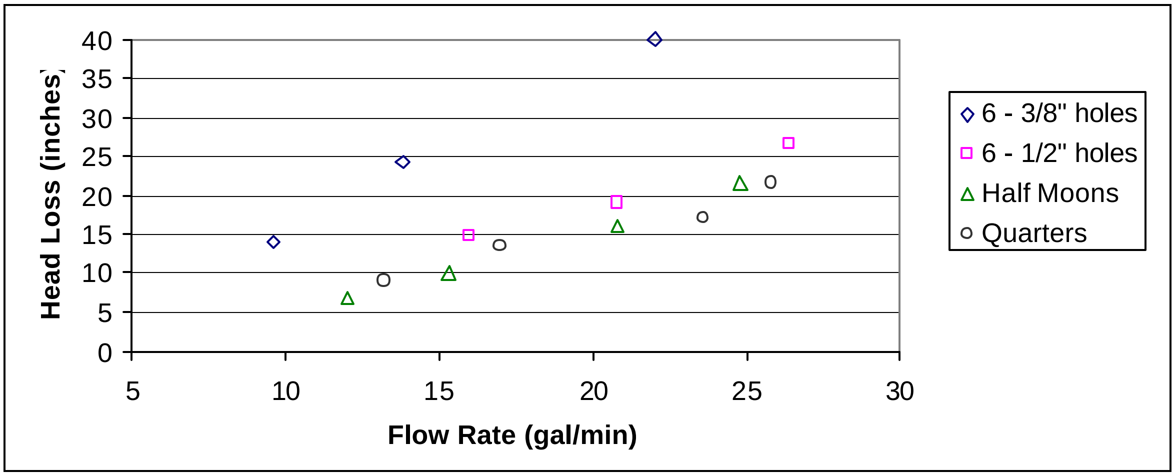


Figure 2 - Head Loss of Check Valve Designs

the hole size, the flap needs to be large enough to cover and seal on the outer edge; cutting the flaps from bicycle tubes requires having a crease in the flap. Attempts to remove the creases were unsuccessful. Therefore, we are recommending that local research in Mahadaga be done to find rubber material (probably from truck tires tubes) that would be stiffer and from which the flap could made without creases.

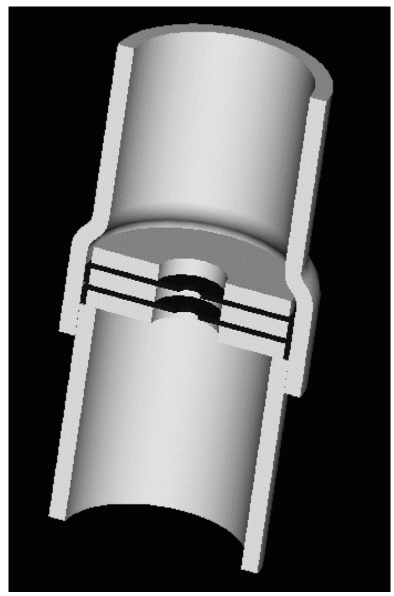


Figure 3 - Double rubber disc seal

The final seal that was chosen consists of two rubber discs supported by three PVC discs (Figure 3). Initially during testing one rubber disc was tried. Leaking during testing was erratic. Once a PVC disc was fully sealed by extending the rubber disc around the outside edge, the single seal did not leak with static head. When pumping commenced, however, water readily squirted through as the seal failed due to the piston's horizontal motion. A tighter seal did not help to relieve the geyser. Providing an additional rubber and PVC disc mitigated the problem very successfully. Also, due to the minimal friction applied as compared with the total actuation force, a tighter ¼ inch hole was chosen over a 3/8 inch hole. We believe this will help in the overall prevention of leaks. As the piston rod deviates from vertical, it has to straighten out the "bunched up" seal due to the rubber hole being much smaller than the piston rod. Only once it has deviated this much does it begin to break the seal around the rod. Testing confirmed this reasoning.

Finally, the wearing of the tighter seal does not seem to be a problem. This is an area where we would like additional testing to take place as we only experienced one failure during our entire testing time. We noticed three things at the time of failure. First, the seal began to leak water as though it only had one rubber disc. Secondly, when we took the seal apart, slight cracks at the holes had propagated creating the failure. Third, surface cracks had formed where the rubber discs contacted the hole edge of the PVC discs. We believe these to be the result of cyclic loading. Remedies for the problems are

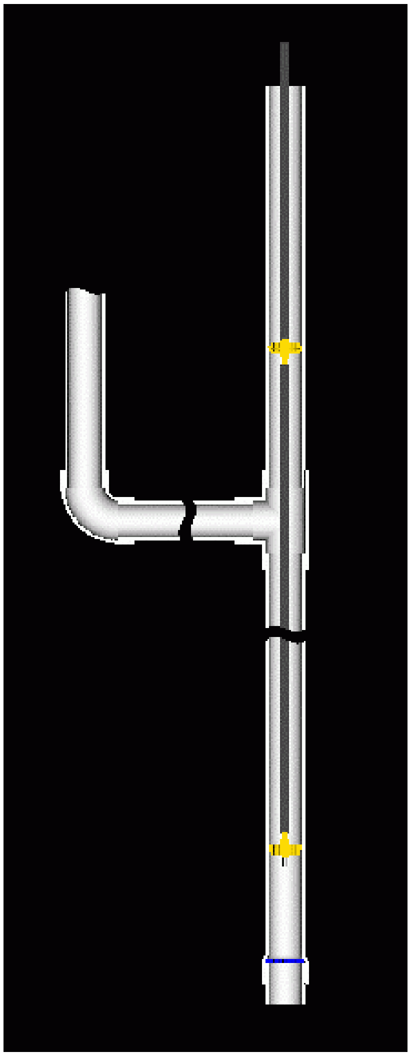


Figure 4 - Dynamic seal alternative

to create the rubber disc hole without any sharp tools except a hole punch, and to file the edges of the PVC hole so that the cyclic pumping action does not pull the rubber disc against sharp edges.

Rejected Dynamic Seal Alternative

The rubber seal was chosen over a double check valve design (Figure 4) due to the complexity needed to construct the dynamic system. Also, it would require the pump to either be extended further out of the well or moved further into the well. The first case would force the vertical extension of an already tall actuation system and the second case would require the partial removal of pump for repairs (something that the nationals do not seem to have a propensity to do).

As in any design, the final product is always a function of the alternatives that are chosen. In our design we opted for a non-moving seal around the piston rod rather than allowing the seal to ride with the piston rod in an extra chamber. This second piston would, in essence, be a single-piston pump with the lower portion of the pump in Figure 4 being the rower pump. A major difference from the non-moving seal is that this design outputs the water on the down-stroke of the piston rather than on the up-stroke as the rower pump does. In order to accommodate for this design, an extra length of PVC pipe would need to be added above the tee joint and another short piece of steel rod would be necessary to maintain the piston at the correct distance from the actuation devise. These changes complicate the pump and require many additional materials. This design also presents more problems when attaching it to the actuation device. In order to keep the actuation a manageable size, the top of the piston shaft needs to be as low as possible. With the current support for the pump, the tee joint is placed level with the top of the well wall. If we need to extend a piece at least 24 inches above this point, the construction of the actuation device becomes more difficult and less accurate.

The static seal that we chose is not without its challenges, but the reduced size and complexity drove us to this decision. The action of the current actuation device (a lever arm) also suggests that the majority of the work is done on the piston's up-stroke as the lever's down-stroke is the more powerful motion.

There are obviously different actuation methods that can be utilized to remove the necessity of the work occurring on the piston's up-stroke. We are not basing our decision solely on this but on top of some of the other reasons this does play a role. Keeping everything simple makes construction and repairs more understandable for the Burkinabe people, which will in most cases lengthen the life of the pump.

2 Design Process and Construction

Our design process began with an analysis of a current problem that we witnessed in the water system that was installed in Burkina Faso. The information that we gathered from our testing and conversations with the local people prompted us to address several major issues. Most of the driving factors of the design came from the Mahadaga environment.

The first major issue that we needed to address was how to eliminate the need for a second pump (See discussion of the seal in 1.3 Solution).

After determining the basics of our seal design, another major issue that we needed to address from an engineering design perspective was the forces and losses in the system. We analyzed each portion of the pump (Figure 5) and determined the forces and head losses; losses are due to bends, pipe friction, and area reductions (in the piston and check valve). Through fluid analysis we were able to estimate a required input force and the local forces on the pump. This was done in two stages: static and dynamic.

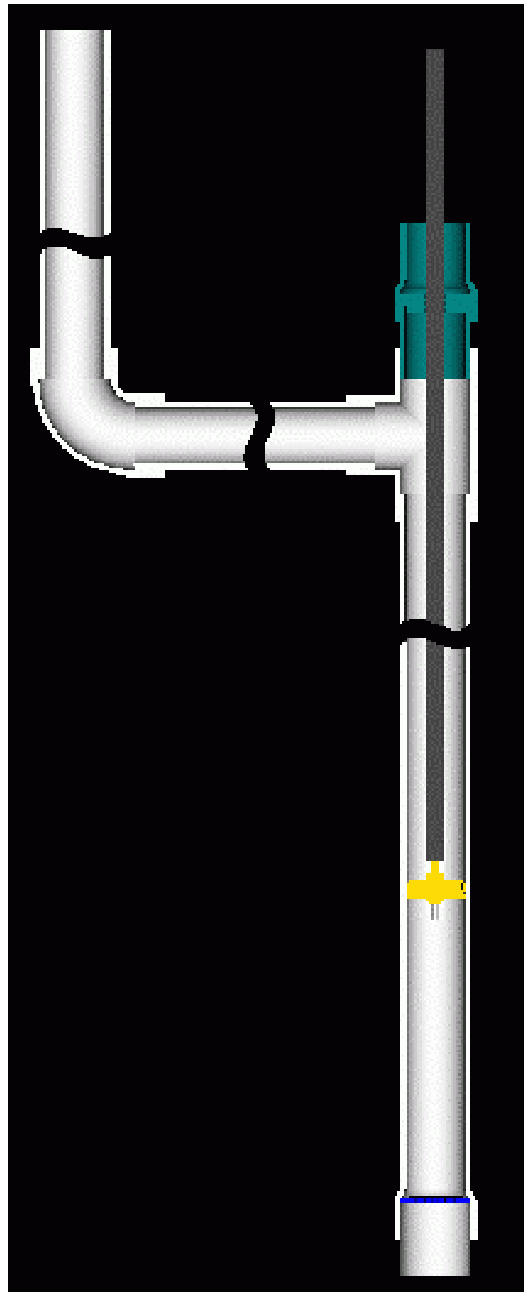


Figure 5 - Integrated Pump Design

There were several questions about nature of the force relationship that required us to do some testing to prove our theories. As it turned out, we determined that the dynamic effects are minimal at the flow rates we are expecting. The only portions of the pump that had significant dynamic head losses were the piston valve and the foot valve. To determine numerical values for these losses we constructed a test setup that allowed us to measure the head losses across several different check valve designs at different flow rates (See Appendix for Check Valve Testing Setup).

The design and construction of the test setups was one of the hardest parts of this process. Our original design was constructed in a loop that would allow us to circulate the water in either direction to simulate the opening and closing of the valves. The loop idea turned out to be impossible due to the restrictions in available piping materials. In order to make the setup work, we needed to disconnect the trailing end from the rest of the tube and allow the water to exit the setup with a smaller amount of resistance. A second feature of our design that needed to change in order to get better results was the orientation of the entire structure. Our original design had the entire setup on a horizontal plane. This proved to be somewhat problematic in achieving the proper pressure on the downstream side of the check valve. At first we propped up the output side slightly and this helped somewhat but was not consistent. We ended up orienting the pipe vertically to more accurately simulate the conditions it would experience in operation. The results of these tests helped us to choose the design of check valve and foot valve.

Another significant head loss characteristic that we needed to consider was the behavior of the valves under a static load. Not only does the valve need to allow the water to pass through it easily, it also has to effectively stop any water from flowing back through the valve under the pressure of 35 feet of head. We determined that the rubber flap on the half-moon and quarter-moon shaped holes could not support this amount of pressure during full-scale testing. The six - 1/2 inch hole check valve can support the pressure if the rubber is somewhat stiffer than a single layer of bike tube. This is the solution that we chose and seemed to offer the best combination of sealing and low head loss.

Along with check valve considerations, the specifics of the seal needed to be designed and tested. We constructed a miniature prototype of the pump that had a full-scale model of the above ground portion while truncating the bottom portion to only three feet to allow us to test the seal without using an actual well. Our simulated well was a 55 gallon drum with water in it. For testing purposes, we wanted our model to assemble and disassemble easily. Therefore we slid the sealing disks into a flared piece of PVC without gluing them. We ran several static tests in order to determine the amount of leakage there was with 12 feet of head. Our tests resulted in random data that we could not explain. The data was not consistent from one test to the next even with the same seal design. After some troubleshooting, we tried wrapping the edges of the disks with rubber to eliminate any leakage around the sides of the seal. This adjustment made it so that there was no static leakage. Dynamic tests with this seal showed that there was some leakage through the seal while the rod was in motion but the volume of this leakage was not significant.

After completing the testing on the individual areas, we implemented a full-scale test. Several major obstacles needed to be overcome to create useful system. One of these was simply a need to support the 15 feet of pipe that projects vertically into the air. After several options were considered, we were able to borrow scaffolding to support the above-ground portion of the pump. Another major question arose when we considered how to measure flow rate while maintaining a constant water level in the well. This was a problem because our method of measuring flow rate in the past was to collect the water in a calibrated bucket and measure the time to fill a specific volume. Due to the constraints of our test well, using this method would significantly change the water level during the testing process (See Table 1). To avoid this, we had to constantly circulate the water back into the well. In order to measure the flow rate we had to introduce a flow meter into the system. The flow meter requires a constant flow; the pump's output is very intermittent. We had to create a system for dampening the output flow to the point that we could obtain consistent and accurate flow values. We developed a system that directed the output of our pump into a bucket with a bulkhead fitting in the bottom. Connected to this fitting was a hose that fed the water through a flow meter and then returned it to the source.

Location	Well diameter	Water level drop per gallon
Grantham	6.5"	7"
Mahadaga	48"	1/8"

Table 1

This setup worked initially to some degree but our original bucket hole size would not allow the necessary flow rate. It behaved rather peculiarly. It would not flow fast enough most of the time, but then it would flow out very quickly and empty the bucket. This phenomenon seemed to be related to a funneling effect that was occurring. The hole was enlarged, but the effect continued. Our solution to this problem was to add a 5 foot section of 2 inch PVC pipe on the bottom of our bucket before we adapted to the 1 inch hose. This eliminated the funneling action that was occurring and sufficiently dampened the flow.

The result of all this work was a test setup that allowed us to test the flow rate while maintaining an approximately constant water level. With this in place we were able to conduct full-scale tests that helped to show the effects of the changes that were made to the pump.

Figure 6 - Pump output and water return/dampening system

3 Implementation

3.1 Construction

In our full-scale test setup we found that the foot valve (Figure 7) leaked, even though, for the ½ inch hole version, a stairwell 35 foot head test leaked minimally. A problem that we saw in the testing prototype was that, after we lifted the piston rod 15 inches and the water level in the outlet pipe rose 15 inches, the piston rod would slowly sink back into the riser pipe along with the water level after we let go. The water level should not have changed. The measurement for this water level decrease was 9 inches. Once the piston rod handle was stopped by the PVC at the top of the seal, the water level did not drop any more (even after a 20-hour period). Examining the foot valve after several pump extractions, the rubber flap was found stuck in the holes, which allowed the water to drain back into the well. Yet, for the particular time described above, no observable flap misalignment was discovered. Our conjecture is that with the cyclic motion of the pump the flap becomes askew. One possible remedy for this problem could be restraining the foot valve away from the flare edge at the bottom of the riser pipe. The current design restrains the foot valve against the flare edge where the flare slopes back to the original size of the riser pipe. The curve of the pipe, if the valve flap has too large of a diameter, can prevent the flap from closing during the checking action of the water, allowing water to leak through. By positioning the foot valve lower, the flap will not be obstructed by the flare edge or any possible contaminants preventing the flap from sealing. The difficulty in restraining the check valve is in seating the foot valve against screws or gluing the foot valve in place permanently (eliminating the ability to replace the valve without cutting off part of the riser pipe).

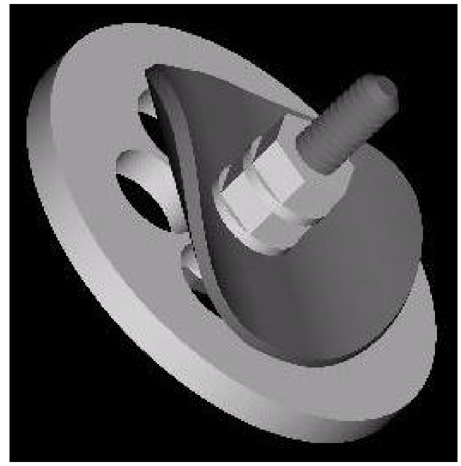


Figure 7

Once the check valve is restrained, we discovered that sealing it became a major issue. There are two options for sealing the foot valve. The first is to simply glue the check valve in the bottom of the pump. When we glued in the foot valve on our prototype, our prime was held for over 24 hours. The downside to glue is that replacing the valve is impossible without having to cut off the bottom of the pump. The alternative is to have a circular rubber piece with the hole design cut into it that would function like the extended rubber disc in the seal—sealing off the edges. We tried this at one point but did not make the disc large enough to seal entirely around the edges. This is something that we hope will be pursued in future testing.

Another possible point of leakage is the bolt hole that mates the flap to the PVC valve. If the hole is drilled too large, water will be able to seep through, especially under high pressures. The bolt can only be tightened so much before the rubber begins to deform and lift up at the edges. The bolt hole in the flap cannot be too small or the rubber will bind up and cause similar issues as at the ends of the flap.

A specific design necessity that seems to be needed for the foot valve is a flat piece of rubber that is of greater thickness than a bicycle tire tube. Thin rubber is too easily deformed by the pressure of 35 feet of head, allowing water to seep out the holes. Also, there needs to be at least 3/16 inch of clearance between the outside edge of the valve holes and the outer edge of the valve flap. This clearance gives the flap enough of a PVC seat for it to make a tight seal despite the water pressure pushing the rubber flap into the holes, bringing in the outside flap edge slightly.

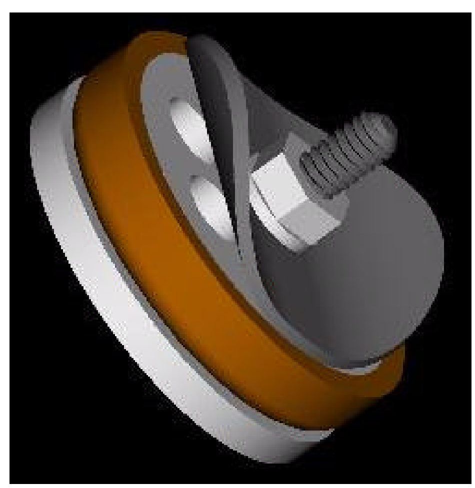


Figure 8 - Piston check valve

Let us consider the components involved in the piston's check valve (Figure 8). Beginning with the piston rod, there is a limitation in the customizability of the check valve due to the ½ inch threaded rod and the materials available to attach to the rod. To continue with the connection that is currently in use, we are forced to bolt a PVC disc to the bottom of the rod for rigidity of the check valve. To provide a seal with the walls of the riser pipe and to diminish unnecessary friction, leather cups were chosen. Since the summer of 2000, when the WAP rower pump was first installed, these cups have had great success with minimal, if not negligible, wear. With the addition of lard as a lubricant, the friction is minimized while maintaining a seal for the checking action. Within the leather cup lays the PVC disc that is able to have a myriad of hole arrangements cut into it. These hole arrangements, though, have to line up with corresponding hole arrangements in the bottom of the leather cup so that water can flow through with minimal head loss. To maintain the PVC disc's seat in the leather cup and to support the bottom of the leather cup during the up-stroke, a PVC piece that will not interrupt the flow is tied through a hole to the bottom of the leather cup. The tie's purpose is to maintain an open channel by prohibiting shifting. Through all of these pieces: the PVC disc, the leather cup, the PVC piece, and the rubber flap, a bolt is tightened to bring the pieces in line and to their working position.

With the rubber flap on top, it is particularly important to consider its sizing. Should one maximize the coverage by going all the way to the inside edge of the riser pipe? If this is done, then the flap's edge is sitting on top of the thin edge of the top of the leather cup. Under the pressure of the water at approximately 30 feet of head, this discontinuity will most likely allow water to seep under a possibly raised edge. If this does not create a problem, then an advantage is provided, in that hole arrangement designs can extend further to the edge of the PVC disc. If this cannot be done, the flap's edge should be trimmed back so that the edge is short of the leather cup enough so that binding does not occur. The critical factor in the valve flap's design is its weight and proximity to the edge of the hole design. At this point in our research and experience, it seems that an 1/8 inch seat is the minimum that should be attempted with a quality weight, flat rubber flap. Weight is critical due to the pressure and cyclic loading that the flap will experience. If the rubber is weak, flimsy, folded, and/or close to the edge of the holes, it will leak due to the folds (incomplete seal against the PVC disc), the rubber folding into the holes, and/or the pressure of the water head will push the rubber into the holes (dimpling the rubber and causing only a thin line seal to occur between the hole edge and the flap).

With this background we attempted to reevaluate what materials were available to attain maximum benefits. In trying to increase the weight of the bicycle tire rubber, we first tried to laminate two pieces together. Using glue that is for PVC, we found it to be more of a lubricant than an adhesive. Finding another glue in the shop area, we applied it to two clean pieces will successful adhesion. A possibility that may work, though more complex, involves tying PVC halves to the upside of the rubber flaps. This way, the flap is still allowed to open and close as necessary, but the PVC takes the pressure force and supports the rubber from slipping into the holes. The PVC was attached by drilling two holes through both the rubber and the PVC and running a piece of string through and tying it off. This may leave the pump with a small leak, though.

Another area that is a problem with bicycle tire tube rubber is that the diameter of the flap cannot be too large or it will have creases in it. The creases cannot be removed. Ironing and boiling had no significant change on the rubber's creases. Therefore, for the pump, we recommend that a tire tube rubber other than a bicycle's be used. Truck tire tubes are available in the Mahadaga area (See Truck Tire Tube

Availability in Appendix). These would be excellent since if they did have creases, they would be further apart, and they would also be of a heavier weight.

3.2 Operation

At the conclusion of our testing we found that the pump performed extremely well. As one can see from the results given in Figure 9, the pump was able to attain a Flow Volume Factor (FVF) percentage close to, if not exceeding 100%. The FVF is a ratio of the actual output volume per stroke to the theoretical volume displaced by the piston per stroke. (In some sources, the FVF is the Mechanical Efficiency.) It is able to exceed 100% because of the inertia of the water as it is lifted out of pump.

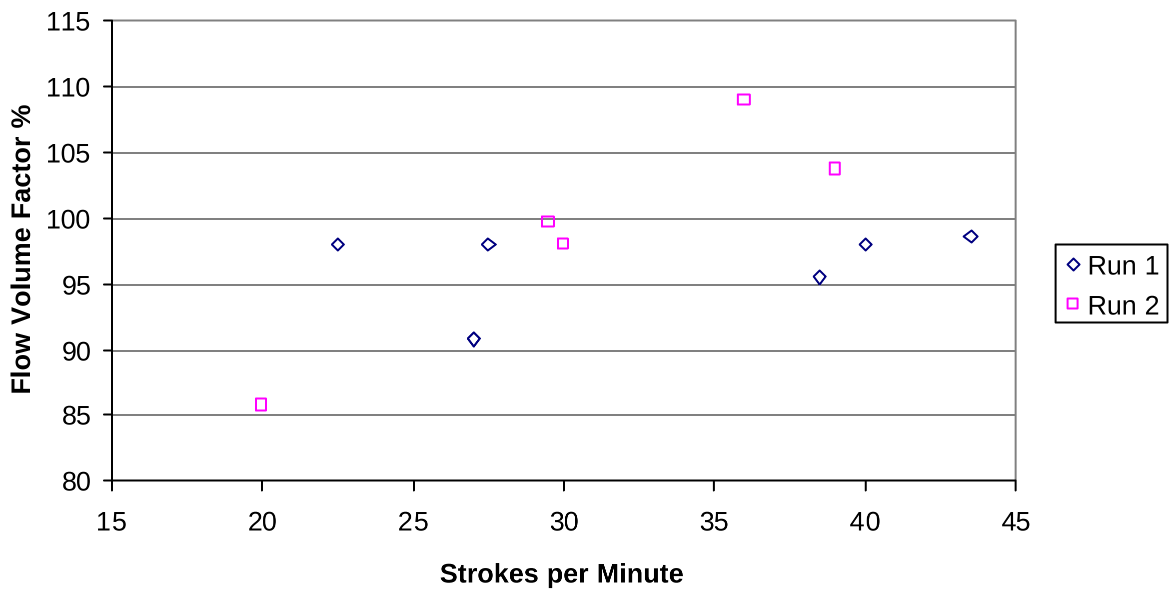


Figure 9 – Flow Volume Factor for a 15 inch stroke length

4 Schedule

See Gantt Chart in Appendix. Overall, we were able to stay generally on schedule. The testing of the full-scale prototype took a little more time than we expected as we ran into leaking problems. When those problems were solved, the testing went very quickly.

5 Budget

ITEM	UNIT LENGTH	QUANTITY	UNIT PRICE	TOTAL
2" PVC pipe	20 feet	2	$15.00	$30.00
2" PVC Tee	N/A	1	$2.00	$2.00
2" PVC 90° Elbow	N/A	3	$2.00	$6.00
½" steel rod	12 feet	2	$10.80	$21.60
2" leather cup	N/A	1	$0	$0.00
1/16" rubber sheet (bike tire tube)	feet	1	$2.00	$2.00
Nuts, bolts, and washers	N/A	1	$5.00	$5.00
			Production Pump Total =	**$66.60**
Items used for more than one pump				
Propane torch	N/A	1	$0	$0.00
Propane tank	14.1 oz.	1	$5.00	$5.00
PVC cement	8 oz.	1	$3.00	$3.00
PVC primer	8 oz.	1	$3.00	$3.00
			Total =	**$77.60**
Testing specific items				
2" PVC Union (Sch. 80)	N/A	1	$15.00	$15.00
Clear 2" PVC pipe	8 feet	1	$38.40	$38.40
Clear 2" PVC coupling	N/A	1	$10.60	$10.60
			OVERALL PROJECT TOTAL =	**$141.60**
Purchase price for items in Burkina Faso				
2" PVC pipe	20 feet	2	$11.76	$23.53
2" PVC Tee	N/A	1	$1.96	$1.96
2" PVC 90° Elbow	N/A	3	$1.63	$4.90
½" steel rod	10 feet	2	$16.34	$32.68
Nuts, bolts, and washers	N/A	1	$5.00	$5.00
			Production Pump Total =	**$68.07**

6 Conclusions

Our pump will be a successful addition to the Mahadaga clinic's garden. We were able to eliminate the need for a second pump and the pump was able to attain at least 35 feet of head. An instruction manual for repairs and reproduction was compiled and approved by a person in industry (See Pump Instruction Manual in Appendix). It utilizes only parts that are available in Burkina Faso. Though we were unable to obtain a flow rate of 9 gal/min that can be sustained for 10 minutes, we believe that the amount of force and the ability to fill the storage barrels in a timely manner will be attainable. An Burkinabe adult male should be able to run the pump for 10 minutes at 6 gal/min with fatigue (See Fatigue Testing in Appendix).

7 Recommendations for Future Work

Further testing can be done to see if a smaller pipe diameter would produce a better force to volume output ratio than the current 2 inch pipe. This can be done with just the riser pipe, only the output pipe, or both. The problem that will arise, though, is a necessary redesign of the piston and foot valves if the riser pipe diameter is reduced. Also, extended fatigue testing on the components can be completed to determine weak areas so that future pumps can be strengthened and/or that owners are aware and are able to repair promptly with the best parts. If truck tire tube can be obtained, testing can be done to see if the added thickness without creases will solve the problems with the bicycle rubber. Finally, the actuation's interaction with the pump could be analyzed for optimum stroke length, stroke rate, and angle of deflection of the piston rod entering the pump.

The difficulty of our work lies in the limited appropriate materials that are available for construction. The purpose of Dokimoi Ergatai, the organization under which WAP works, is to utilize materials that a particular culture can obtain readily. And in Mahadaga, Burkina Faso, there is not much that is available. PVC for the piping actually comes from the capital, an 8 hour drive away by vehicle. Though a lot of work has been done in Mahadaga and at Messiah, a specific study for new uses of local materials to Mahadaga may be justified. This should be done on an existing trip and not on its own for efficiency's sake.

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APPENDICES

Specifications (of Final Prototype)

	English	Metric
Minimum Head Requirements		
Ground Level to Water Level:	25 ft	7.5 m
Ground Level to Tower Output:	10 ft	3 m
Output Flow Requirements		
Minimum Flow at Minimum Head: (for 15 inch stroke length at 30 strokes/minute)	6 gal/min	22.7 L/min

Dimension Constraints

PVC riser pipe fits into an 8 in. diameter well. All other PVC connections and piston shaft connection are outside of the well.

Priming

Maintains prime, so that after 24 hours, a 1 strokes is required to output water.

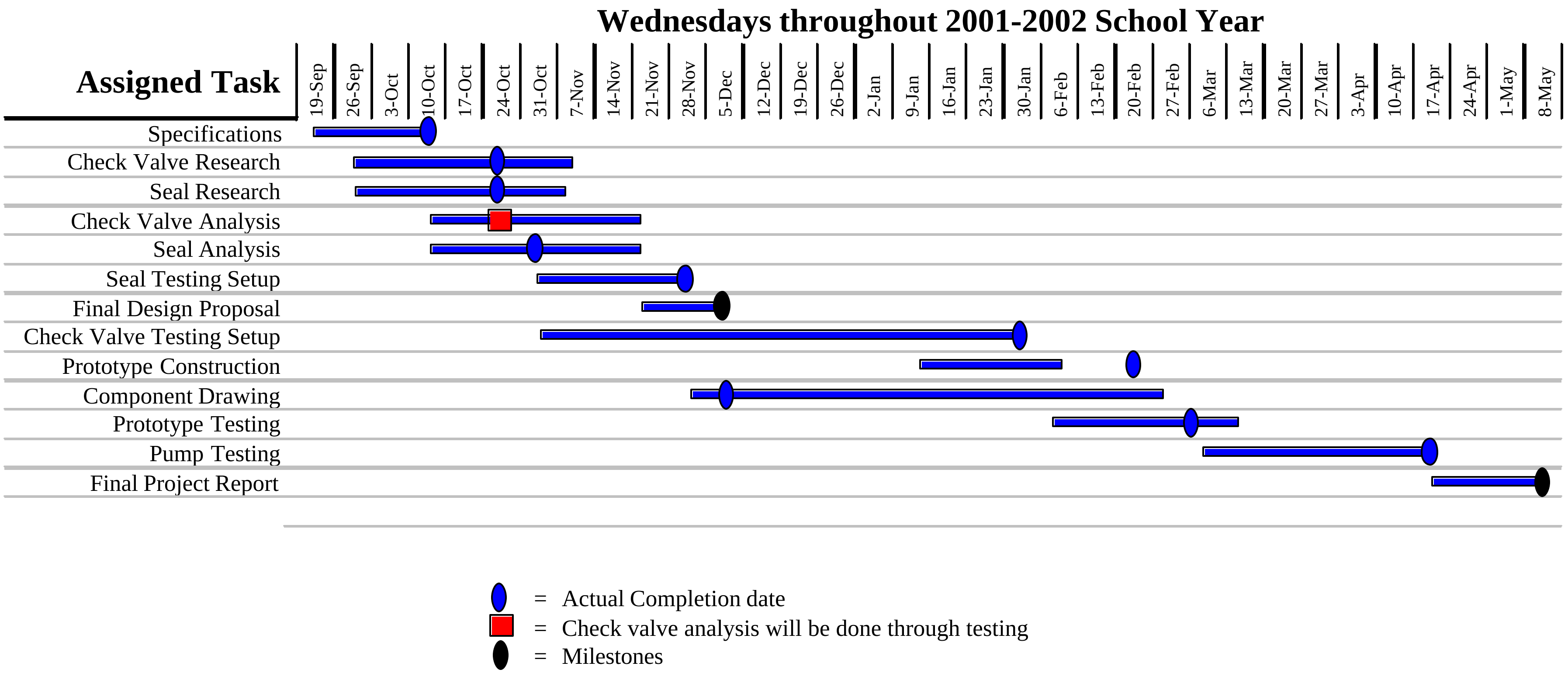
Materials

Actuation Connection Type: Threaded Connection on Piston Shaft (12mm - diameter)

Constructed from materials available in Burkina Faso.

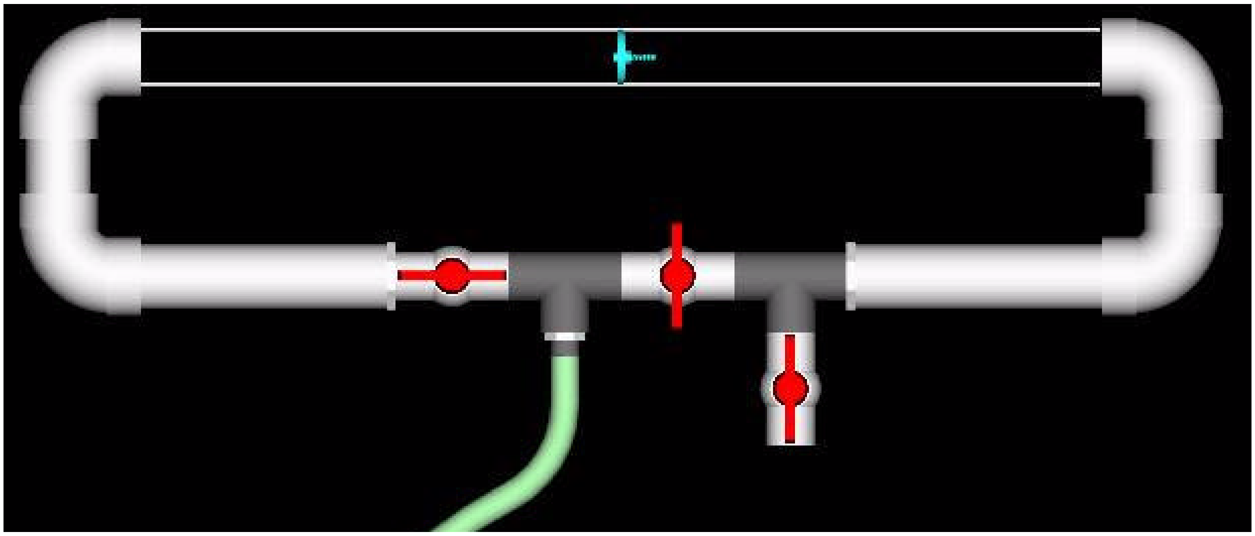
Material Cost: 52,020 CFA ($US - $68)

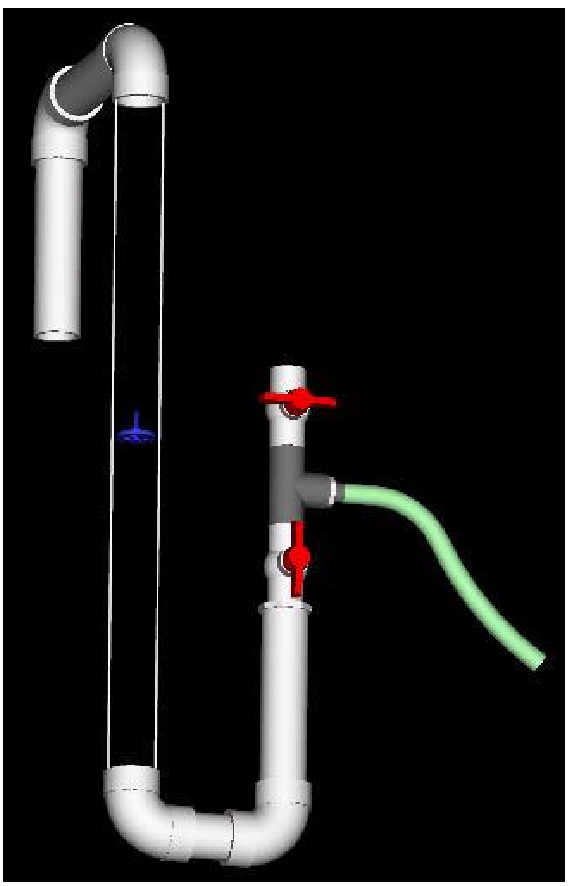
Gantt Chart



Wednesdays throughout 2001-2002 School Year
Assigned Task
19-Sep
26-Sep
3-Oct
10-Oct
17-Oct
24-Oct
31-Oct
7-Nov
14-Nov
21-Nov
28-Nov
5-Dec
12-Dec
19-Dec
26-Dec
2-Jan
9-Jan
16-Jan
23-Jan
30-Jan
6-Feb
13-Feb
20-Feb
27-Feb
6-Mar
13-Mar
20-Mar
27-Mar
3-Apr
10-Apr
17-Apr
24-Apr
1-May
8-May
Specifications
Check Valve Research
Seal Research
Check Valve Analysis
Seal Analysis
Seal Testing Setup
Final Design Proposal
Check Valve Testing Setup
Prototype Construction
Component Drawing
Prototype Testing
Pump Testing
Final Project Report
= Actual Completion date
= Check valve analysis will be done through testing
= Milestones

Check Valve Testing Setup





Fatigue Testing

April 20, 2002

I've done some more thinking about [the actuation motion—lat pull-down], and I'm convinced it's not really a matter of strength but endurance if you are expecting individuals to do this work for 8-10 minutes.

Let me digress and review -

The motion you are using can be done once by most men at a force equivalent to 85% of their body weight. Once you get below a certain amount of force, strength is somewhat still important, but the ability to continue becomes much more a matter of endurance. For the movement you are looking at, this would be true, in my opinion, when individuals are moving approximately 20-25% of their body weight.

I did a little experiment on myself and was able to do 16% of my weight for 8 minutes at 300 reps (1.6 seconds per rep), and I was not fatigued at the end. A bit bored but not really tired - I certainly could have gone on considerably longer. For me that was a resistance of 24 pounds. It all depends what typical weight (for the average male) that you want to use, I suppose. The key is that since this is endurance oriented, there will certainly be a training effect for those who choose to do this; i.e. it will get easier with time.

If you still need to determine HP or some other factor related to the work being done, let me know, if you think I may be able to help. Or if there is other information you needed that I didn't provide.

The average male should be able to sustain a power output of 50 - 70 watts for at least 10 minutes (perhaps even 100 watts).

Good luck,

Doug

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Truck Tire Tube Availability

Hi Mike,

Surprise! Our e-mail worked well this morning (not always the case), and I already have an answer to your question.

Daniel, our Burkinabé business agent, says that truck tire rubber is not usually available right in Mahadaga, BUT can almost certainly be found within 25-50 kms. (at Namounou or Diapaga).

Hope this helps. Thanks for the work you're doing.

God bless,
Kathy
[Kathy is the business secretary at the SIM country headquarters in Ouagadougou, Burkina Faso]

-----Original Message-----
From: Michael Foster
Sent: Thursday, May 09, 2002 12:45 AM
To: Kathy Cail
Subject: Truck tires?

Hello Kathy,

My name is Mike Foster and I work with the West Africa Project and Dokimoi Ergatai at Messiah College, PA. My senior project this year has to improve the existing design of the rower pump being used in Mahadaga. To help finish up my report I was hoping that you could tell me how available truck tire rubber (the inner bladder) is in Mahadaga.

The reason I am asking is that we have been trying to use bicycle tire rubber. To get rubber flaps large enough to cover our check valves, we have had to cut into the crease that is in the tire. This crease doesn't flatten under the water pressure and allows water to leak through. Our thought
is that the larger rubber bladder of truck (or any vehicle tire) would have a creases far enough apart so that a flap could be cut out without a problem.

If you could get us this information before Monday, it would be fabulous. Understanding how communication is in Burkina, we know that will probably not be possible. Thank you for your help!

Mike Foster