Mechanical Engineering Senior Design I
EGME 4810

Project Proposal
SIM PVC Hand Pump

SIM Hand Pump
2014-2015

Faculty Advisor
Dr. Darren Holland

Submitted by
Tyler Baechtle, Jonnah Baker, Ryan Frazier
Tyler Griggs, Matt Lee, Kyle Nelson, Tori Shrum

Report Submitted
Monday, September 29, 2014

Abstract

Serving in Mission (SIM) has designed a hand pump for use in rural Bolivian wells, currently in the area of Vacas, Bolivia. In order to truly help the people who need the water pump, the SIM well pump project was designed to be self-funded, self-led, and self-propagating within Bolivia. Initial use of the pump has been very promising, as several pumps have been implemented and are frequently used by the people of Vacas. However, SIM does not have the means to thoroughly test the design, which is why partnership with the senior design team is beneficial. Ultimately, the senior design team's project goal is to optimize the pump performance and durability. Longevity testing last year showed the pump to be long-lasting, although they only had one complete test. Thus, to further confirm the design, this year's team will focus on conducting long-term testing to measure the exact pump lifespan. This project will focus on building an additional pump for testing purposes, testing the pump to failure, incorporating a more realistic pump angle in testing, investigating motor use for pumping, studying filter designs, analyzing last year's PVC seal design, creating a pump design calculation tool, recording pump performance and recommending improvements for components that fail or underperform. There is currently a test apparatus from last year, but further enhancements will be made in this project. The resulting test data indicating pressure degradation, component wear, and pump fatigue will be used to implement and guide further design improvements. Through all changes, a pump cost of approximately $25 will be maintained, with all components available in Bolivia. Estimated at $2290, the overall budget will be primarily driven by instrumentation and data acquisition technologies.

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Introduction

Every day women and children in rural Bolivia have to carry water to their houses, livestock and gardens. This is a physically strenuous process which simultaneously introduces pathogens to both the well water supply and the water being transported. This exposure is potentially deadly to the children and adults who use and drink the water. Water comes from wells located near people's houses. Historically, the primary method of drawing the water from wells has been a rope and bucket. A new method is necessary to alleviate the burden of obtaining water and keeping it pathogen free.

Serving in Mission (SIM) is an organization working in Bolivia and one of its current projects seeks to provide a sustainable solution to this problem. This organization defines a sustainable solution as one that is self-funded, self-propagating, and self-led with respect to the native Bolivians. SIM utilized an existing hand pump design made from locally available PVC parts and modified the specifications to be more affordable, easier to build, more reliable and higher performing. Already, SIM has seen interest from communities in Bolivia – people are building pumps and spreading the idea. The concern has now become determining the effects of prolonged, daily use of these pumps on the different components of the pump, as well as accurately mapping performance throughout its designed lifespan. After the first year of testing, additional needs have developed. Alternate seal designs and a field method to measure pump performance could help expand the life of pumps currently in service. And the development of publishing tools, motorized designs, and altered pumps capable of operating in high head conditions will aid in the adaptation of the hand pump to new environments.

As Jesus said in John 4:13-14, "Everyone who drinks this water will be thirsty again, but whoever drinks the water I give them will never thirst. Indeed, the water I give them will become in them a spring of water welling up to eternal life." While these hand pumps will help to satisfy the physical thirst of the Bolivian people, it must be remembered that the only true solution for their spiritual thirst is to share with them the soul-quenching Gospel of our Lord Jesus Christ.

"*Like cold water to a thirsty soul, so is good news from a far country." –Proverbs 25:25*

Background Research

INTRODUCTION

Background research was conducted and gleaned from last year's senior design team over a large area of topics related to the 2014-2015 SIM PVC pump project. Research was needed on technical aspects of the pump and testing desired for this year's project. The research has been divided into three sections: 1) issues relating to pump testing, 2) modifications to the testing apparatus and data acquisition systems, and 3) projects that are looking toward the future of the hand pump. Information was also gathered about the environment in Bolivia that this pump is to be used, and the culture in which the pump will be found. All of these play a role into how the project will be carried out, and what options will be pursued to aid in the goal of bringing clean water to Vacas, Bolivia.

- ***ISSUES RELATING TO PUMP TESTING***

This section contains research pertaining to the testing of the pump. This includes issues such as longevity testing, seal designs, effects of the environment on the pump, and pump efficiency.

SIM REQUEST FOR LONGEVITY TESTING

Based on SIM's needs, our testing should test the pump to at least its operational life (60,000) cycles. The 2013-14 team conducted one longevity test during their time. Wear of the seal on the PVC cylinder is one cause for concern after a large number of cycles, and should be a key feature monitored in testing. It was determined that multiple longevity tests need to be conducted for the pump in order to provide valuable data and to identify other possible design improvements. (2013-2014 PVC Hand Pump)

ISSUES IN DETERMINING LIFETIME OF PUMP

We hypothesize based on our research that the main issue that we are dealing with in the lifetime of the pump is the piston valve seal, which was discussed in detail in the senior design report from last year. SIM states that the average lifetime for pumps installed in 3rd world countries is about 9 months. The team from last year did not come up with any concrete conclusions as to the lifetime of this seal, and therefore it will be one of the primary objectives we are aiming to meet this semester. We are anticipating that all of the other parts of the pump stay in working condition longer than the piston seal. However, other types of failures may include, but are not limited to: hand or crank breaking, and sand or dirt abrasion on various parts.

EFFECTS OF ABRASIVES ON PVC PUMP PERFORMANCE

As with any water well pump, debris, silt, sand and other foreign materials present the possibility of damaging and affecting the performance of the pump if not properly accounted for. According to the report from the previous team, this problem of debris entering the PVC pump was one causing some difficulties for SIM. It is noted in the report that there were difficulties with the foot valve becoming clogged while in use, resulting in down time for the water pump and difficult maintenance and cleaning.

In order to begin to address this issue, last year's Senior Design team at the end of their project had begun to develop a simple filter to add to the foot valve. This filter however has had very limited testing performed to see how it will impact the overall performance of the pump and how it well it will do in filtering debris from entering the pump. The filter component is shown below in Figure 1. The terrain in which the PVC pumps are being installed is Vacas, Bolivia which consists of mainly sandy and rocky soil ("Welcome to The Bolivian Water Project"). Opportunity for sand or gravel to enter the pump brings the need to further look into the effects of abrasive materials on the PVC structure. PVC has been widely used for half a century now mainly due to its high durability, strength, resistance to wear and its stable chemical properties ("What Makes PVC Important?"). Though it is also commonly accepted in the piping and plumbing industry that any form of potable water is not considered abrasive to PVC, the effects on the pump should still be considered (PVC PIPE).

To test for abrasion resistance Taber Abrasion testers are commonly used. The measurements from this testing can help to provide comparisons from one material to the next. Though considered very resistant to abrasion and wear, PVC also has been found to be less resistant then some other plastics of its kind as shown in Table 1 below ("Comparative Abrasion Resistance of Various Polymers"). Compared to polypropylene pipe (PP) and High Density Polyethylene (HDPE) in one test performed by ADS (Advance Drainage Systems), PVC lost five to eight times more mass due to abrasion ("Abrasion Resistance of Polypropylene"). This supports the need to look into the effects abrasive material in the water may have upon the components and overall performance of the PVC hand pump.

Figure 1. Foot valve filter designed by the previous senior design team.

Table 1. Comparative Abrasion Resistance of Various Polymers

(Comparative Abrasion Resistance of Various Polymers)

Material	**Weight Loss (mg)**
thermoplastic urethane	0.4-3.2
ionomer	12
nylon 6/10	16
nylon 11	24
HDPE	29
polytetrafluorethylene	42
nitrile rubber	44
nylon 6,6	58
LDPE	70
rigid PVC	122
natural rubber (tread formulation)	146
SBR (premium tread formulation)	177
SBR (tread formulation)	181
plasticized PVC	187
butyl rubber	205
ABS	275
neoprene (polychloroprene)	280
polystyrene	324
Taber abrasion, CS17 wheel, 1000 gm weight, 5000 revolutions Ref: Handbook of Thermoplastic Elastomers, Litton Educational Publishing, 1979	

PVC SEAL PROS/CONS

There is little to no searchable results of PVC itself used as a seal for PVC. However, we can still compare the properties of PVC to rubber, leather, and other materials and apply that to a hypothesis of its pros/cons when used as a seal compared to rubber or leather.

There are several reasons why PVC is a beneficial seal material. First, the coefficient of friction between PVC and PVC is less than PVC and rubber, or PVC and leather (2013-2014 PVC Hand Pump). Second, the PVC wears less than rubber over time (PVC Europe; 2013-2014 PVC Hand Pump). Moreover, the PVC seal is potentially easier to fabricate by hand. Also, PVC has a low melting point of 160°C (compared to the 400°C of rubber and leather), which makes the material malleable and aids fabrication (Wilkes; eHow; Calcinations).

PREVIOUS SOLUTIONS

The Senior Design team on this project from last year determined various methods for creating a good piston valve seal. These included: a tire rubber seal, a leather seal, a cloth seal, and a PVC on PVC seal. The cloth seal was very effective at filling the gap between the piston valve and cylinder, but wore out quickly. The tire rubber seal was very effective, but hard to make. Various methods were attempted to manufacture this rubber seal properly. It was very difficult to manufacture because its dimensions had to be very precise.

EFFECT OF CYLINDER BENDING AND CURVATURE ON PISTON PERFORMANCE

According to their reports, the 2013-14 senior design team investigated new piston designs that would be both easier to manufacture, resistant to wear, and provide increased performance. With women and children as the primary users of the hand pump, the force required to operate the pump is also of concern, and is greatly impacted by the piston seal design. Through testing, the 2013-14 senior design team found that a piston seal created from PVC provided the best overall results when it came to force required to pump and performance.

When testing these PVC seals, the team did not take into account the angle in which the pumps would be installed in Bolivia. According to Dr. Holland’s theory, the flexing in the long cylinder that extends into the wells may have caused a decrease in the performance of the PVC seal, and has in turn eliminated the benefits of the PVC seal from that of the old rubber design. For the PVC seal to function smoothly a thin film of water needs to be able to occur between the piston and cylinder. This film of water helps to create the seal and lubricate the piston which originally provided for the decreased force necessary to operate the pump. With the cylinder curving it is believed that the piston is then rubbing against the cylinder wall, breaking the water film seal and also hindering the ability of the water to act as a lubricant to the piston, and in turn hindering the performance of the piston.

CALCULATING EFFICIENCY LOSS

When it comes to analyzing a system there are many ways to measure efficiency. On the surface, efficiency is the equal to the measure of work into a system to the measure of work out of the system. As it applies to the PVC hand pump, efficiency measures how well the pump converts power to useful work moving the water (Richards).

The main measurement used in determining a pump's efficiency is flow rate. The efficiency of a motor or mechanically driven pump would be determined by the amount of power the motor consumes in comparison to the volume of water the pump is then able to move. Computational fluid dynamics is also used at times to provide analytical calculations or predictions of the efficiency of a component or system. In the case of the Senior Design team from 2013-14, due to the nature of the PVC Pump system, they determined a CFD model would not be a beneficial means of evaluating the pump.

Instead the team relied mostly on flow rates, and volumetric flow measurements they could take with simple flow meters (2013-2014 PVC Hand Pump). When making a characteristic or part change to the pump system, the team last year would measure the instantaneous flow velocities and use these measures to determine the effectiveness of a change (2013-2014 PVC Hand Pump). Losses were also analyzed and found that due to the simplicity of the PVC hand pump design the head losses were extremely small (2013-2014 PVC Hand Pump).

The design team from last year also attempted to measure the power going into the motor, which would provide another method for determining efficiency, however after several attempts they found that the benefits of this added measure were not worth the time and effort to obtain them.

Finally another way efficiency can be measured is through force input to flow rate output. Using strain gages a force can be measured and from that force, work can be determined by knowing the distance over which this work occurred (Kurtus). Knowing the manual work going into the pump can provide another measure of the efficiency to transmit that work into producing water flow.

POLYETHYLENE vs. POLYVINYL CHLORIDE

Polyethylene (PE) and polyvinyl chloride (PVC) are “the plastic pipes most often used for underground utility construction.” The primary difference between the two types is how they are joined together. Another interesting feature of PE is that it is “the only often pipe material that is truly flexible” ("Understanding the strengths of PE, PVC").

• *MODIFICATIONS TO TESTING APPARATUS AND DATA ACQUISTION SYSTEMS*

This section contains research concerning improvements to the testing apparatus and systems used to obtain data.

REFINING INSTRUMENTATION TO MEASURE PUMP EFFICIENCY

An improvement that could be made to the instrumentation, as mentioned by the team last year, was in regards to the flow meter. They noticed that the flow meter would often become clogged with debris from the well. In order to avoid this, they suggested installing a mesh upstream from the flow meter to avoid false flow readings. A possible solution suggested by Dr. Holland could be to use a expansion tank to catch the debris by installing a slanted mesh just after it, forcing debris into the tank, avoiding clogging the pipe and meter, and allowing for easy clearing. See the following excerpt from the 2013-2014 senior design report, pages 28-29.

"Throughout testing, we experienced a few issues possibly related to the introduction of debris in the flow meter, which we hypothesized may be the cause of some inconsistent flow data as shown in the Test and Evaluation section. *Figure 24* shows the fine mesh at the entrance to the flow meter in both its clean and partially clogged condition. When obstructed, pressure builds up in the rest of the line.

Figure 2. The photo on the left portrays the fine, unobstructed mesh at the entrance to the flow meter prior to testing. The photo to the right shows debris accumulated in the mesh during testing on April 1, 2014. The nature of this material is still being analyzed as the team seeks to determine whether this debris is actually PVC shavings from the pump itself or merely particulates from the well being used for testing. The same material seen in the picture to the right was also found around the piston seal."

OP AMP CIRCUIT TO AMPLIFY STRAIN GAGE SIGNAL

In last year's project, strain gages were installed on the upper part of the pump to measure the force required on the up stroke and down stroke to pump the water. The team last year noticed that the strain gages recorded forces from the PVC deforming under pressure as well as the pumping force. See the excerpt below from the 2013-2014 senior design report, pages 29-30.

"At the onset of developing the test system, our team treated strain as one of the potential indicators of degradation over the lifecycle of the pump. In order to ensure the test apparatus actuated the pump with a similar force profile to that of a typical pumping motion by hand, we placed a uniaxial strain gauge on the front and rear of the 1" PVC pipe directly under the handle, with a stopper made of expanded 1" PVC pipe directly below to protect the strain gauges from coming into contact with the handle guide.

To determine the strain due to axial forces compared to moments on the PVC handle, we used a quarter-bridge setup for each of the two strain gauges…

Hence, while the strain data allowed the team to effectively compare the pump forces between the apparatus and a typical user, the precise force is not known due to the pressure-induced axial stress experienced at the top of the handle. In order to better

> extract the actual pumping force, we intend to move the location of the strain gauges from the PVC pump handle to the coupler of the test apparatus itself."

To avoid this, strain gages were placed on the steel handles of the pumping apparatus, which attached to the pump. However, since steel deforms much less then PVC, the signal from these strain gages was too low. So, we hope to implement an op amp (operational amplifier) circuit to amplify the force signal so that we may gather more accurate force data, greatly contributing to testing. Op Amps work by amplifying the input signals up to 10^5 times larger, so only a small input signal is required to allow the op amp to work in its linear range (Parr, 16). Thus our small voltage is amplified so that the data can be read.

In relation to required materials, we have the Arduino from last year's team, so we simply need to obtain appropriate strain gages and op amp(s). A quick search on Amazon.com showed prices for op amps and op amp sets ranging from less than a dollar to about $20. The circuit we need seems relatively simple. For strain gages, some uniaxial strain gages cost from $70 to $50 (omega.com).

Implementation of the circuit seems relatively simple. After discussion with electrical engineering professor Dr. Gerald Brown and initial research, it appears we only need a Wheatstone bridge connected to an op amp, which then feeds to the Arduino. We also need at least two "dummy" resistors for the Wheatstone bridge, and at least two strategically sized resistors connected to the op amp to achieve the proper gain ("431/531 Class Notes 9", 37).

After discussing issue further with Dr. Gerald Brown, it appears we can use a half bridge connection with the two strain gages and two high-quality 120 Ohm resistors. From there, the left and right outputs can be connected to an op amp, set up as a difference amplifier. This configuration is also a benefit because it will allow a lot of noise in the signal to be canceled out. To set up the op amp as a difference amplifier, we also need two resistors to connect to the op amp of a certain values to give the needed gain (Tretter). It appears from last year's senior design report, the recorded strains were about -70 to 70 microstrain (see Appendix C, p. 83 of the 2013-2014 Senior Design report).

TESTING APPARATUS MODIFICATIONS

The 2013-2014 senior design team gave recommendations for testing apparatus modifications, including shortening the component test inlet pipes as well as adding plastic bushings to the linkage connections of the apparatus. The following research was done as a result of those recommendations.

BEARINGS

The basic principle of a bearing is to provide support and to allow for relative motion between parts. For our particular application the testing apparatus uses rotary motion. All bearings are either considered to be mechanical contact (sliding, rolling, or flexing) or non-contact bearings (fluid film, magnetic). The two primary types of bearings to be considered by our team is either a ball bearing or a roller bearing. For low cost and low load applications ball bearings are a logical choice. Also to increase the effectiveness the bearings should have some type of grease inside and seals on the exterior. In order to choose the right type of bearing the following formula may be used (Slocum).

- n = speed rating
- ν = ISO specified viscosity value
- dm = bearing pitch or (OD+ID)/2
- F = applied load
- q = ISO specified heat flux (function of surface area and bearing type)
- A = ISO specified area (function of bearing type)

IMPROVING TEST APPARATUS FLUIDITY OF MOTION

The senior design team of 2013-14 designed and manufactured a motorized test apparatus so that they could simulate pump usage over several thousand cycles. An objective of the design was to replicate the typical human pumping motion. While as a whole the finished test apparatus came close to achieving this goal, there is still room for improvement.

The main issue with the apparatus is that the motion is not very ‘fluid’—the mechanism tends to speed up and slow down as it pumps. This is due to the varying nature of the load on the motor. There is a slight difference in the load as the water is lifted during the upstroke and forced out the handle on the down stroke. Additionally, during the transition between strokes there is no force. The previous team attempted to compensate for these changes by constantly adjusting the pumping speed with their motor controller. However because of limitations in regards to calculation speed, their hardware was unable to adjust the motor speed quickly enough.

We believe that finding a better way to regulate this pumping speed effectively will allow us to more closely simulate the human pumping motion. This in turn should provide us with more accurate test data. Research into this issue has yielded two possible solutions.

FLYWHEEL

A flywheel is a component in many mechanical systems used to store kinetic energy. For example in the early 1900s flywheels were widely used on internal combustion engines to create a more constant power output. These flywheel engines were designed to operate with very few power strokes, dramatically reducing fuel usage. When the engine would fire, it would speed up the flywheel, storing up kinetic energy. The flywheel would continue to revolve between each power stroke, providing a nearly constant supply of output power. Thus, the addition of a flywheel could take the intermittent power supplied by an engine and 'smooth' it into a constant supply of mechanical power.

Theoretically, the inclusion of a flywheel on the test apparatus could provide a similar benefit. A flywheel could be made by adding weight to the bicycle wheel or, if needed, by replacing it entirely with a heavier component. While the electric motor provides constant mechanical power, the load in the pump is not constant and adding a flywheel could help create a buffer in this system. When the pump load is lowered on the up stroke, the motor's energy will be used to spin the flywheel faster. Then as the load increases on the down stroke, the flywheel's kinetic energy is used to reduce the load on the motor. This process continues for each pumping cycle, helping to create a more 'fluid' pumping motion.

Figure 3. This image shows the use of a flywheel on an antique engine. (*Gas Engine Magazine*)

There are some constraints that must be considered when incorporating a flywheel into a design. The energy stored within a flywheel is governed by the equation:

This equation shows that the kinetic energy held in a spinning flywheel is determined by its moment of inertia (I) and its angular velocity (. It should be noted that the angular velocity is a much more significant factor in this equation than the moment of inertia. It is possible that the moment of inertia required for a flywheel can exceed the available space in a design; similarly the necessary rotational speed may not be ideal or possible. These factors will need to be taken into account if a flywheel is chosen to be included in a mechanical system.

COUNTERWEIGHT

Another possible solution is the use of counterweights. Historically, counterweights were used on pump jacks to aid in the pumping of oil from deep within the soil. During operation, the motor lifts the counterweight during the lower-load down stroke. Then as the load increases with the up stroke, the gravitational force acting on the counterweight aids the motor in pumping the oil. Balanced correctly, the counterweight helps create a much more constant load on the motor. Adding a counterweight to the test apparatus could produce similar benefits.

There are several negative factors to using counterweights that will need to be considered. It is very likely adding counterweight will increase strain on the motor, metal frame, and bearings. The mass and location of the necessary counterweight may not be ideal or even possible for this application.

Figure 4. This shows a typical pump jack design with counterweights. (*GRABCAD*)

- *PROJECTS LOOKING TOWARD THE FUTURE*

Several areas were researched that may help to expand the availability and effectiveness of the SIM pump project to new environments.

FIELD METHOD OF MEASURING PUMP PERFORMANCE AND EFFICIENCY

It would be useful for the missionaries to be able to quickly go out to the wells and collect data. There are several ideas for how to make this possible. First, a chip could be installed on the pump that logs number of cycles as a function of time that is accessible onsite, or via satellite to lab location (HCJB Global Technology Center). Another idea is to measure inlet and outlet water pressure and use the differential to calculate what the theoretical head should be, compare that to the actual head to find efficiency, and observe the change in the pressure differential measurement over time to see the change in the performance of the pump (Pumps & Systems). Another idea is to measure the volume of water that is pumped in one hand pump cycle and compare it to the theoretical value, as well as over time, to observe change in volume of water pumped in one cycle to evaluate pump seal performance.

ONLINE TOOLS

In the design process for a pump, there are many calculations that go into it. Missionaries (as well as senior design teams) would highly benefit from a program that does the calculations, and perhaps even modeling, of a pump in an effort to save time, energy, money for prototypes, etc. Thus, the following research has been done to investigate the feasibility and options of creating such a program.

There is information on the Microsoft website regarding making a calculation spreadsheet that can be made in Excel and then implemented to the internet that allows website users to run their own numbers. MATLAB is also an option. The other sources found, which are associated with a fee, upload the online calculator to a website and format it for the user. There will be many calculations and formulas needed. It is also important to know that temperature correction for water is negligible as long as the water does not freeze. Figure 5 and 6 give a visual depiction of what pump system may look like.

The following calculation process should be useful in sizing a pump:

- What is the required/desired flow?
- Define TDH (Total Dynamic Head)
    - Calculate friction loss
        - Friction loss = total length X friction loss (straight pipe) factor + friction loss (fittings)
        - Friction loss = (_____’ X _____’/_____’) + (__’ X __)
        - Friction loss = _____’ + _____’
        - Friction loss = _____’ Head Pressure
    - Now we can calculate TDH!
        - TDH = pumping level + vertical rise + friction loss
        - TDH = _____’ + _____’ + _____’
        - TDH = _____’

- Now that we know the TDH and required/desired flow, we can select a pump from a performance curve.
- Which pump/motor combination will deliver the required/desired flow at the calculated TDH?

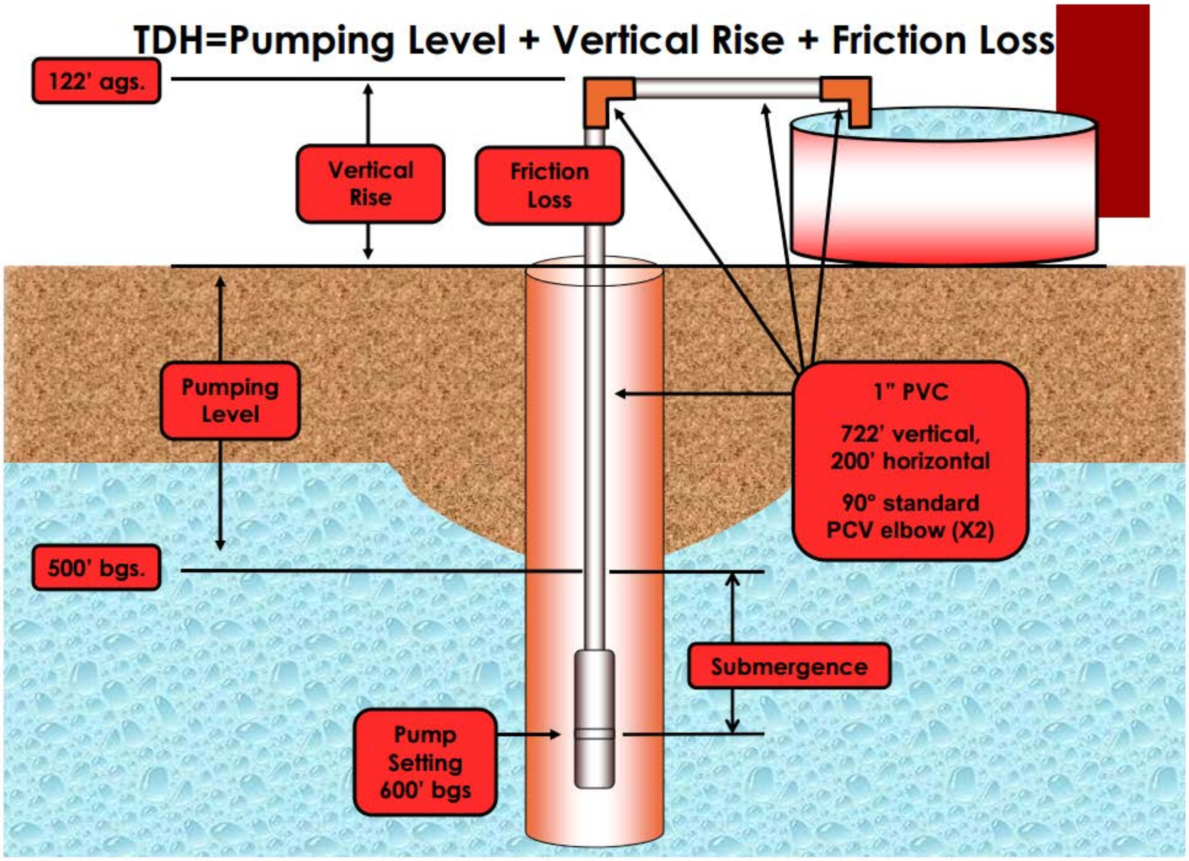


Figure 5. Depiction of a typical pump system and the various components that must be accounted for when sizing a pump. (*Indian Health Service*)

Regarding changing the dimensions of a pump, thinner PVC is generally better because it is lighter and, thus, easier to install and pump.

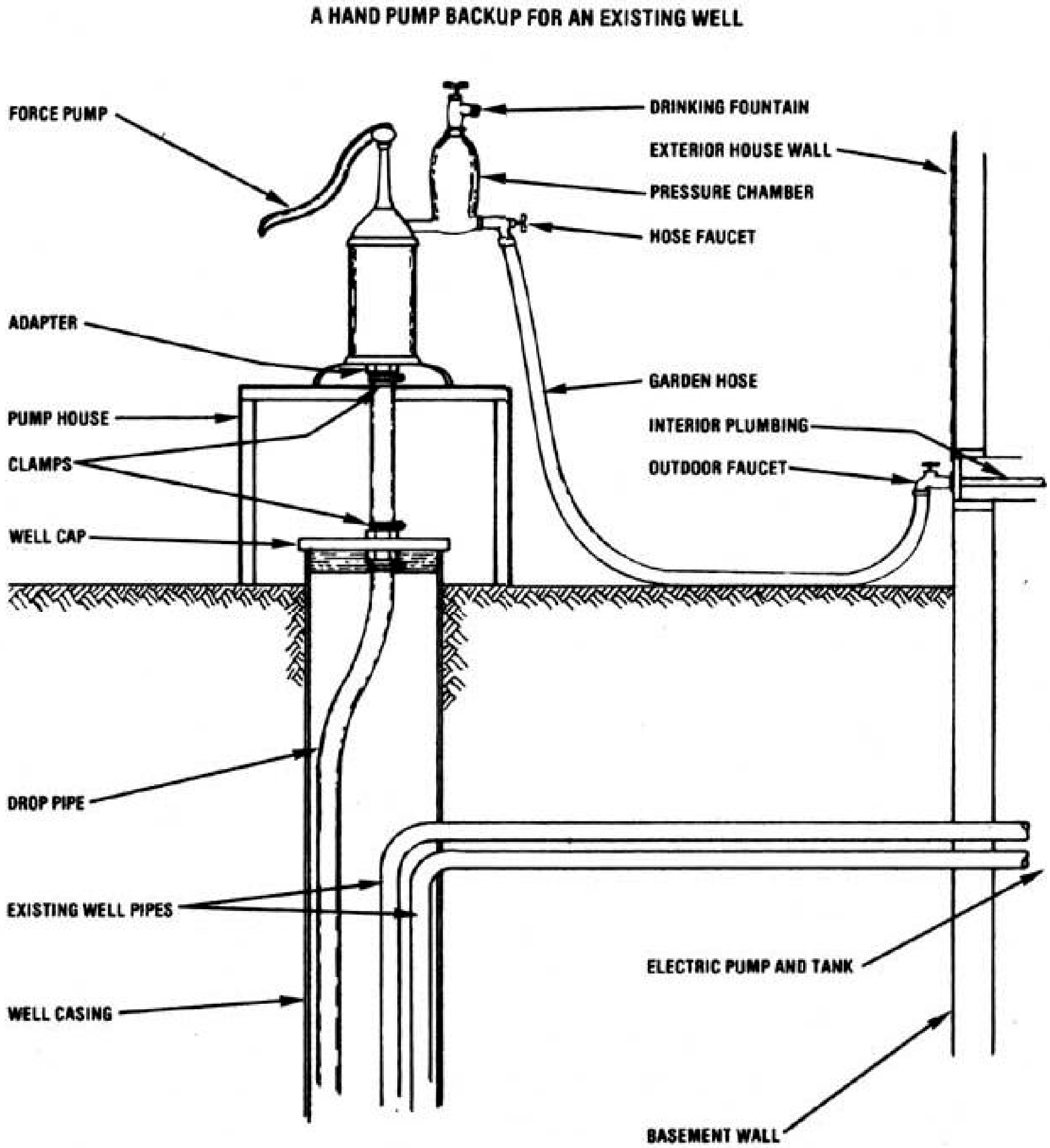


Figure 6. Depiction of typical hand well pump (*Mother Earth News*)

PUMPS USED WITH SMALL SCALE IRRIGATION

Helping to further irrigation is a project that could be extremely beneficial to rural Bolivia. There are three types of pumps investigated for irrigation purposes: jet pumps, hand pumps, and bicycle pumps. Jet pumps operate quietly, do not need to be primed, may be used in wells, and may be used in conditions where water depth changes. However, this type of pump may be less economical, more difficult to install, inspect, repair, and require periodic impeller adjustments to maintain efficiency (Irrigation Pumps). Hand pumps are cheap and simple for easy maintenance. Bicycle pumps can be less exhausting to use than hand pumps, are cheap (although possibly not as cheap as hand pumps), and boosts the pump's efficiency (Engineering for Change).

MOTORIZING ISSUES

Many of the Bolivian pump users are reported as desiring a model with a motorized design. This is a direct quote from Dale Harlan, (a worker for SIM who understands the demands for our PVC pump down in Bolivia)

> "There is considerable interest in about 25% of our PVC hand pump users in upgrading to a motorized version. Of course, their interest is quite cost sensitive --- so the cheaper the better.
>
> About any cheap, common general-service single phase electric motor can be found in Bolivia. I suggest that you look around the USA and find the best price / performance model, evaluate it, and if it looks promising, then I can verify that something similar is available in Bolivia.
> As far as prices in Bolivia, a very good first estimate would be to look at Ebay or Amazon prices and then add 70%."

Following his suggestion for research indicated that a cheap, general service single phase electric motor costs about $150 on the lower end. Adding 70% would make it about $255.

ISSUES INVOLVED WITH DESIGNING PVC PUMP MOTOR INTEGRATION

Rural Bolivians are greatly interested in motor integration to the PVC pumps. Motors could make their society much more efficient, saving time from pumping by hand so often. However, one issue is cost. Motors are very expensive, and energy is expensive. The availability and cost of motors/motorized pumps in Bolivia is also a limiting factor.

HIGHER HEAD ISSUES

Another aspect of the pump that could be developed over the year is a pump for higher head conditions, such as 20 meters. An important application for this research is that the SIM PVC hand pump could be taken and applied to other locations in need of clean water that have lower water tables, for example, nations in Africa.

According to the World Health Organization in an article entitled "Water lifting devices", a standard direct action hand pump is limited to a depth of approximately 12 meters, which is about 40 ft. The limiting factor is the human's ability to lift the water. Because there are no levers or flywheels that add a mechanical advantage, the human must lift the actual weight of the water being lifted.

SOLUTION TO HIGHER HEAD ISSUES

The World Health Organization has developed a simple solution for maintaining a low cost design while being able to achieve a much higher head (15-45 m, or 50 – 150 ft) called the *deep-well piston hand pump.* This pump design is very similar to the direct action pump, only it has a lever arm for the pump handle, and is generally made with a much stronger material. For example, the Afridev (A Layman's Guide to Clean Water) hand-pump has a handle and lever system that consists of primarily steel parts. This is understandable considering that the head of this pump is roughly 80 meters.

Another solution they discuss for achieving higher head is a called a Diaphragm pump. The concept of this pump is to pump water into an expandable "diaphragm" (high elasticity/high density material), placed at the bottom of the well. When this diaphragm is full, the valves switch and the water is pumped up to the user.

SOLUTIONS FOUND THUS FAR

The centrifugal pump is a commonly used, efficient pump. However, due to the priming necessary for this pump to start, it is much better to use this pump to raise water rather than to lift water. This would require the pump to be submerged in the well, which may cause corroding and other issues.

INTRODUCTION TO BOLIVIA

ABOUT BOLIVIA:

Cedarville sent a team to Bolivia June 2014 to test the implementation of the PVC seal idea as well as to gain understanding of the Bolivian environment and project more. A PVC seal was implemented at one location. The condition of the PVC seal seems to be the same as that of the rubber seal, according to reports so far. During the Bolivia trip, the team also installed a pump at the well of a rural school in Vacas, Cochabamba. ("Vacas" means "cows" in Spanish.) The people were so excited about it that they came out to see how the process was going and support us, not to mention cooking lots of food to thank the team. The kids all came out of school and sang, and a boy performed a theatrical recitation on the well. The community is obviously in support of these additional water sources.

There are other water sources in Vacas that are available (but not necessarily dependable or sanitary). There is a rainwater runoff source at the school, but it only has water available seasonally – although relatively very clean. There is also a piping system from a main community well source, but water is only available every three days to the individuals, and it is not very clean (mainly due to broken pipes in the line that allow contamination). In another location, a water tap provides water from a river which has then been chlorinated. However, reports of small animals getting caught in the system make it less desirable for drinking water.

Though SIM is doing great work with these well projects in Bolivia, it should also be mentioned that there are other organizations helping the Bolivian people of Vacas as well. World Vision and Compassion International are doing a lot of good there. SIM also partners closely with two organizations in Vacas, Alcance Bolivia, and Bolcan. The unity and desire to work together of all of the support organizations allows more needs to be met holistically rather than just providing additional water, and for work to be done in a culturally sensitive way.

The Bolivia team was also involved in water testing of well water and water from the other systems, which proved that most of the water was contaminated. Fortunately, the water is often boiled before drinking, which sanitizes it. However, the food grown is contaminated with this unclean water, and the animals drink this water. This unclean water does cause poor health, as discussed by an Alcance Bolivia leader.

Another important consideration that must be kept in mind when working on the pump is that of the culture of the Vacas region and the people that will be using the pump. As noted by the Alcance Bolivia leader, the people of the region do not have a good concept of bacteria and sanitization. The team learned it has been difficult to help well-owners understand that the area around the well must be kept free of waste so that bacteria does not seep into the groundwater and contaminate the well, or the importance of filter to rid the water of bacteria. People of the region generally do not have an understanding of germs and bacteria, and culturally are not prone to change, believing that they are bound to their poverty. The leader noted that it is important to find ways to show the people on their level of understanding the importance of these measures for clean water and encourage them to take responsibility for the project, believing they can make a good change. This is an engineering challenge, and also a very relational challenge, but also provides great opportunities to build relationships and share God's hope and strength to change.

Above is a picture of some members of the Bolivia team heating the PVC tubing, obviously struggling to get it the right pliability to fit in the other pipe.

Notice the low handle, making the well easy for children to use – as women and children are the main water retrievers. Also, notice the farm animals in the background. Sadly, many people do not keep their animals away from the wells, causing contamination from the feces in the groundwater. A filtration system may be useful to keep them from either drinking the dirty water or needing to use energy boiling it.

The hole next to the well is a safety hazard as well as a possible means of contamination.

Many parts of Bolivia, including Vacas, have very high elevation (11,000 ft.) – The Bolivia team is pictured here on a hike up the Andes Mountains. It is important to keep this point in mind in design, as elevation changes pressure.

The rest of the background information presented here is taken from the 2013-2014 PVC pump team's background research, which is relevant to the project this year:

Our project is primarily working with people living in the Vacas Municipality in the Cochabamba Department (state) of Bolivia. The basic pump design we are testing uses parts that are found locally in this area and is specifically designed for the weather and water conditions found here. While currently limited in use geographically, the hope of the project is that it becomes self-financed, self-sustained and self-replicating- moving to other parts of Bolivia. *Figure 7* displays a typical landscape in the Vacas community.

Figure 7. Typical landscape in Vacas.

Vacas falls at 11,100ft above sea level in the Altiplano region of Bolivia. The Altiplano has an average height of 12,000 ft and holds the world's largest commercially navigable lake, Lake Titicaca ("Altiplano", 2013). *Figure 8* shows Bolivia's location on the South American continent on the left and then Vacas' location in Bolivia on the right.

Figure 8. Bolivia's location relative to South America and Vacas' location relative to Bolivia.

CLIMATE

Vacas' region of the Altiplano is arid to semi-arid. Temperatures vary widely throughout a single day. *Figure 9* shows the average temperatures for a year in Vacas. *Figure 10* depicts the average monthly precipitation totals. The rainy season occurs primarily from October to March and the rest of the year is the dry season. The two seasons define when the people dig their wells, usually in the dry season with the ground is drier and thus more firm. Temperatures occasionally drop below freezing, which impacts pump design considerations.

Figure 9. Average temperature for a year in Bolivia (*www.worldweatheronline.com*)

Figure 10. Average rainfall for a year in Bolivia, reference (www.*worldweatheronline.com*)

As seen in these charts, the lowest the average low temperature gets is 3°C, which is above freezing. Operation will therefore mostly occur above freezing temperatures. Lows going below freezing will need to be taken into account, and the testing plan will need to include subfreezing tests. However, since temperature underneath the ground is always above freezing, it is unlikely that significant problems will occur.

PEOPLE

People in the Vacas area primarily speak Spanish and Quechua. They are mostly indigenous people of Quechuan descent. The main economic source is agriculture. Since the citizens require irrigation, the pump will be very beneficial to grow potatoes, wheat, barley, broad bean and oat and raise livestock. Most water currently available is primarily carried by women and children, requiring heavy lifting and often contaminating the water with pathogens. The purpose of the PVC pumps is to reduce the burden on those who transport water and to provide a more sanitary source.

WATER TABLE

The height of the water table in Vacas varies from rainy season to dry season. In the dry season, when most wells are built due to the relative sturdiness of the soil, and the water table can be as low as 10 meters below ground. During the rainy season, the water table raises, requiring less effort to pump the water out of the well.

ADDITIONAL WATER ACCESS PROJECTS IN BOLIVIA

Multiple other organizations and individuals other than SIM are creating accessible water for Bolivians. The fundamental basis of the pump design comes from EMAS (a Spanish acronym for Mobile School for Water and Sanitation). Wolfgang Buchner, a German engineer, is the founder of EMAS and resides near Lake Titicaca in Bolivia. There he runs the technology demonstration center where he trains locals on all sorts of water improvement systems.

He has helped create a myriad of technologies for inexpensive water access and sanitation including drilling techniques, well improvement, storage tanks, filtration systems, and of course pumps. Videos of water technologies he has designed can be seen here: http://vimeo.com/channels/emas/page:1.

POWERING PUMPS

Horse and wind-powered pumps can provide. These power sources cost very little and require less work for the individual compared to manual hand pumps. Sometimes, windmills are combined with rope pumps in order to supply water for cattle and irrigation systems (Netherlands Water Partnership, 2006). Although these may not be the most efficient or long-lasting pumps, they provide a cheap way to supply large quantities of water to essentials like animals and plants.

There are several viable designs that have been created for cost-effective hand water pumps. Each design is made to fulfill a specific purpose and design requirements. By studying these designs and deciding which ones help to meet the design requirements of this project, the group may be able to combine some ideas and methods to improve the design of the SIM pump.

PVC PROPERTIES

Much of the pump is made out of PVC pipe. The SIM hand pump uses a combination of pressure pipes and sanitary pipes. The sanitary pipe is light and the forces on it are small compared to that on the pressure pipes used. According to the Vacas Water Pump Installation Brochure provided by SIM, the dimensions of the Bolivian sanitary pipe used for the hand pump are an inner diameter (ID) of 37.8mm and an outer diameter (OD) of 40.8mm of DN40 pipe. Pressure pipe is also used in this design. One type that is used is Schedule 40 which has thicker walls and can bear more pressure and force than the sanitary pipe. It is used to make the handle and valve body of the pump. This type of pipe is also good for pipe threading because of the increased wall thickness. Other types of pipes include SDR21 and SDR26 which are thinner walled pipes that are inexpensive and used for the piston rod (Oliver, 2013).

HEALTH HAZARDS

The Materials Safety Data Sheets (Appendix B) give some good information about the safety hazards. PVC becomes pliable at temperatures between 225°F (107°C) and 275°F (135°C) and ignites at temperatures greater than 730°F (Longnecker, 2010) (Sanderson Pipe Corporation). Some of the hazardous decompositions products of PVC are CO, CO2, hydrogen chloride and small amounts of benzene and aromatic and aliphatic hydrocarbons (Sanderson Pipe Corporation). Due to these hazardous decompositions, the risk of overexposure includes irritation of the respiratory tract, eyes and skin (Sanderson Pipe Corporation). There are no major hazards other than irritation of the skin and eyes and displacement of breathable air by fumes – these will be remedied by having good air circulation during melting. Other concerns during melting will be burning hands on flames or through contact with hot PVC. These hazards can only be avoided through careful use of the stove. More information on fire hazards and health hazards can be found on the Materials Safety Data Sheet on the website www.sandersonpipe.com/msds.pdf.

MECHANICAL PROPERTIES

PVC also has several attributes that make it strong and sturdy and a good material to leave out in the sun without too much degradation by its often harmful UV rays. From long exposure to the sun's rays, PVC shows little change in molecular structure and mechanical strength. In particular, tests show that tensile strength and elastic modulus for PVC are generally unchanged due to UV exposure. It is possible to protect above-ground systems exposed to UV radiation by applying a coat of white or pastel-shade PVA paint (Vinidex). There are very simple ways to protect PVC from such exposure.

It is interesting that even though PVC is a viscoelastic material, its creep deformation is very low compared with other plastics due to limited molecular motion at ordinary temperature. Plastics like polyethylene (PE) and polypropylene (PP), differ in this fact, making PVC better for mechanical loading (PVC Europe). This is an important feature in the use of a pump because the material of the pump should not easily wear or weaken over time.

With the knowledge of the properties of PVC, it is easier to know how to work with it when fabricating the pump and its limitations in designing any modifications. Based on the thickness of the walls of the pipes, PVC can be fairly strong, which is important for pumps because they will be used often. Its accessibility, good mechanical properties, UV radiation resistance, and the fact that it has a stable molecular structure makes it a good candidate for a project such as the SIM-pump.

BASIC PUMP COMPONENTS

Dale Harlan with Serving in Mission (SIM) has had extensive influence in the design of this pump and connecting it with the members of the Senior Design team at Cedarville University. He is the liaison between the full-time Australian engineer, Matt, who lives in Cochabamba, and SIM and the Senior Design team. Much of the information about the hand pump, Bolivia and the project as a whole comes directly from him.

ANATOMY OF A HAND PUMP

While there is no official nomenclature for hand pumps, some general terms will be clarified for ease of discussion. The handle is the part which the person pumping grasps. The part moving up and down on the inside of the pump is the piston rod. The outside pipe is the cylinder. The part sealing the piston rod against the cylinder is the piston ring. The valve at the bottom of the cylinder is the foot valve. In the SIM design, the valve on the bottom of the piston rod is the piston rod valve.

REASONS FOR DIRECT ACTION PUMP

In most direct action pumps, the user pushes the handle up and down, lifting water during the up-stroke. The SIM hand pump is unique in that it lifts water on the down stroke and forces it out on the upstroke. *Figure 11* shows the design of a typical direct action hand pump. Since there is currently no lever in this type of pump, there is no mechanical advantage. Therefore, the user must be able to lift the body of water on their own, limiting the application of the direct action pump to shallow water depths of 0-12 m (World Health Organization).

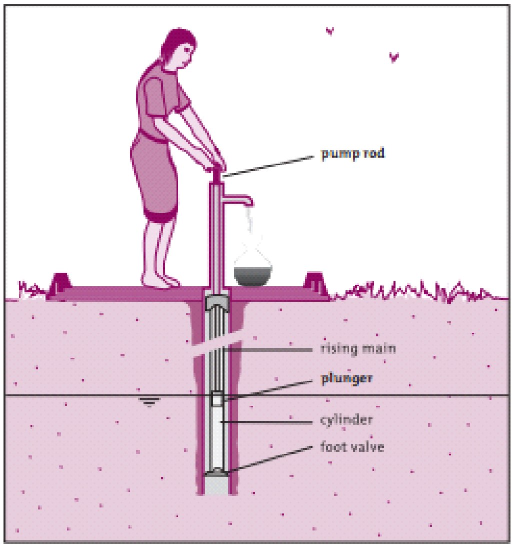


Figure 11. Basic mechanism of a direct action pump

Advantages of this type of mechanism include low costs, availability of materials, and simplistic maintenance. Wear of the seal on the PVC cylinder is one cause for concern after a large number of cycles. Furthermore, for women and children pumping may become difficult for depths close to 10 m (World Health Organization).

TYPICAL PUMP ACTION VS. SIM PUMP

In a typical reciprocating hand pump, such as a suction, direct action, or lever action pump, a long pipe (referred to as the rising main) extends from the entrance point of the well to the cylinder and foot valve. The piston mechanism in the cylinder serves to create an area of low pressure, drawing the water from the well into the chamber through the one-way foot valve. In most reciprocating pumps, water is lifted on the upstroke as a new vacuum is created in the cylinder, drawing in additional water from the well. *Figure 12* demonstrates the piston mechanism utilized in this type of approach (Baumann 2005).

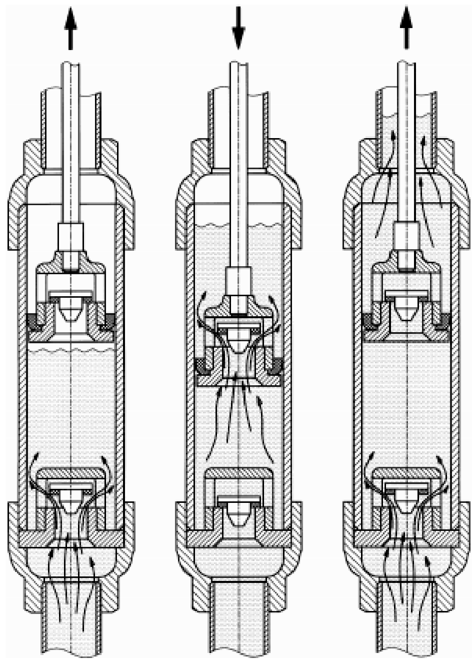


Figure 12. Check valve mechanism on reciprocating hand pumps. (*EMAS)*

SIM PUMPING MECHANISM

Figure 13 shows the EMAS check valve which works the same as the SIM check valve. The mechanism is oriented in such a way that water is lifted on the up stroke. On the down stroke, water is pushed around the top marble and out through the handle. Marbles work well because of their durability and accessibility.

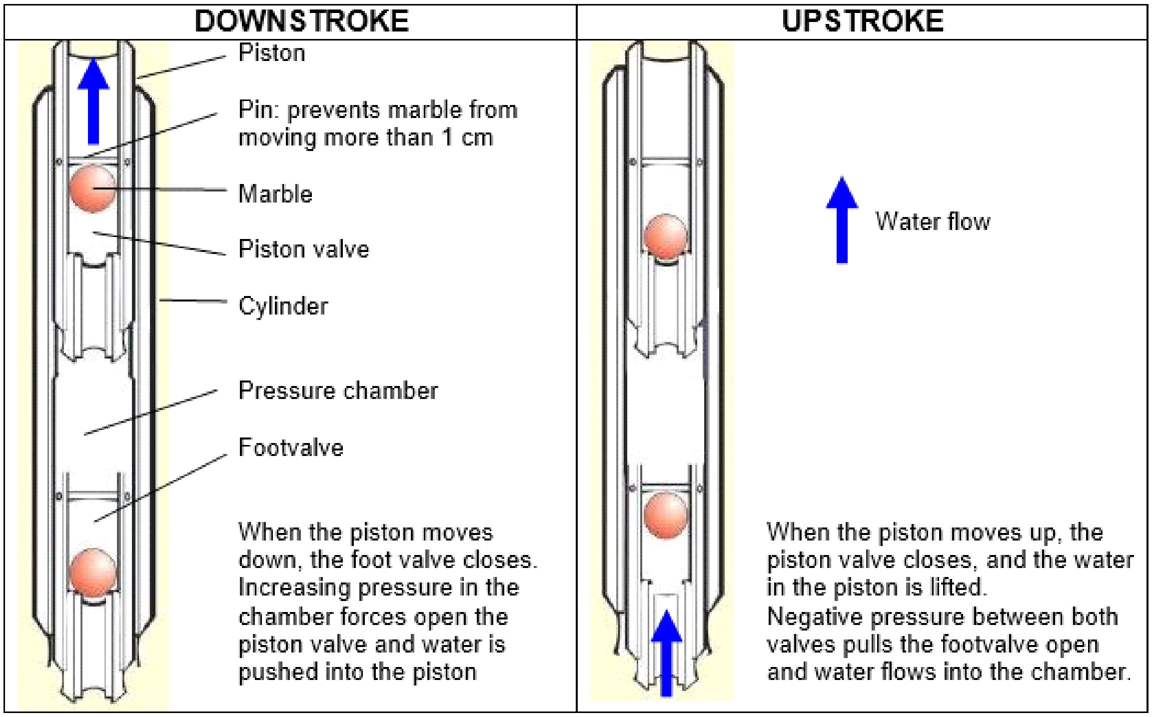


Figure 13. EMAS Check Valve Mechanism *("Mobile School for Water Sanitation")*

The SIM pump operates with check valves, but in the piston rod and the foot valve. The use of a smaller diameter pipe allows for use in deeper wells below the suction limit (Longnecker, 2010). Water is delivered on the down stroke through the piston rod and handle assembly. This means that as the hand pump is being pulled up, water is drawn past the foot valve into the cylinder while the marble at the piston rod valve is seated. This action brings the water into the area between the two check valves. Then as the handle is pushed down, the foot valve is closed, the piston rod valve opens, and water to passes up and out of the pump. This design is convenient for relatively deep (8-10 meters) water wells, but cannot pump water higher than a few meters above ground level (Netherlands Water Partnership, 2006).

SIZING PUMPS

When determining sizing for this type of pumps, it's important to understand the mathematical relationships driving flow rates and friction losses as a result of selected pipe diameters. Intuitively, when decreasing the diameter of the pump cylinder, the same volume of water must flow at a faster rate in order to maintain equal output. The mass flow rate is given by *Equation 1* and solved for the velocity in *Equation 2*.

Where A is the cross-sectional area of the pump cylinder, is the mass flow rate is the density and v is the velocity of the fluid. In a circular pipe, A is calculated by *Equation 3*:

Where d is the internal diameter of the pump cylinder. Finally, *Equation 4* demonstrates the relationship between the velocity of the fluid and the frictional head losses expected.

Here *f* is the friction factor, *L* is the length of the pipe, *d* is the diameter of the pump cylinder, *V* is the fluid velocity and *g* is acceleration due to gravity. To understand the cause and effect relationships of altering the diameter, imagine the diameter of the desired pipe is halved. As a result, *Equation 3* indicates the cross sectional area reduces to ¼ of the original. From *Equation 2*, the reduced cross sectional area translates to a velocity four times that of the original velocity. Finally in *Equation 4*, velocity is squared and diameter is halved so the resulting frictional losses are 32 times greater. Thus, if the diameter of the pipe size is cut in half, the frictional losses increase by a factor of 32.

Therefore, when obtaining materials, designing a test environment, and proposing any optimizations, it is important to remember the magnified impact of any changes to internal pipe diameters.

MATERIALS

Table 2 and *Table 3* provided an overview of the various PVC dimensions and material needs to build the PVC pump. One challenge will be finding components matching those available in Bolivia. Therefore, we will continue to update and refer to *Table 2* throughout the duration of the semester. This information will allow us to find comparable solutions for critical dimensions even if identical PVC pipes are not available. In the US, it is difficult to match pipes with Bolivian pipes because the US uses British sized pipes and Bolivia uses SI system sized pipes. *Table 2* which is provided in the Vacas Water Pump Installation Brochure highlights the total cost of materials required to construct SIM’s latest rendition of the PVC direct action pump. Any proposed modifications will need to ensure that the total cost of the pump does not exceed $25 without sufficient benefits.

Table 2. PVC pipe dimensions overview (water pressure-W.P.)

Nom. Pipe Size (in)	O.D.	Average I.D.	Min. Wall	Nominal Wt./Ft.	W.P. PSI	Avail in USA	Avail in Bolivia
Bolivian Sanitary Pipe							
1-1/2"	1.606	1.488	0.059				Yes
SDR 26 - W.P. 160 PSI							
1"	1.315	1.175	0.060	0.173	160		
1-1/4"	1.660	1.512	0.064	0.233	160	Lowes	
1-1/2"	1.900	1.734	0.073	0.300	160		
2"	2.375	2.173	0.091	0.456	160		
2-1/2"	2.875	2.635	0.110	0.657	160		
3"	3.500	3.210	0.135	0.966	160		
3-1/2"	4.000	3.672	0.154	1.250	160		
SDR 21 - W.P. 200 PSI							
3/4"	1.050	0.910	0.060	0.136	200	Lowes	
1"	1.315	1.169	0.063	0.180	200	Lowes	
1-1/4"	1.660	1.482	0.079	0.278	200		
1-1/2"	1.900	1.700	0.090	0.358	200		
2"	2.375	2.129	0.113	0.550	200		
2-1/2"	2.875	2.581	0.137	0.797	200		
3"	3.500	3.146	0.167	1.168	200		
3-1/2"	4.000	3.597	0.190	1.520	200		
4"	4.500	4.046	0.214	1.927	200		
Schedule 40							
3/8"	0.675	0.473	0.091	0.115	620		Yes
1/2"	0.840	0.602	0.109	0.170	600	Lowes	Yes
3/4"	1.050	0.804	0.113	0.226	480	Lowes	Yes
1"	1.315	1.029	0.133	0.333	450	Lowes	Yes
1-1/4" *	1.660	1.360	0.140	0.450	370	Lowes	Yes
1-1/2" *	1.900	1.590	0.145	0.537	330	Lowes	Yes
2" *	2.375	2.047	0.154	0.720	280	Lowes	Yes
2-1/2"	2.875	2.445	0.203	1.136	300		Yes
3" *	3.500	3.042	0.216	1.488	260		Yes
3-1/2"	4.000	3.521	0.226	1.789	240		Yes
4" *	4.500	3.998	0.237	2.118	220	Lowes	Yes
Schedule 80							
3/8"	0.675	0.403	0.126	0.146	920		
1/2"	0.840	0.526	0.147	0.213	850		
3/4"	1.050	0.722	0.154	0.289	690	Lowes	
1"	1.315	0.936	0.179	0.424	630	Lowes	
1-1/4"	1.660	1.255	0.191	0.586	520	Lowes	
1-1/2"	1.900	1.476	0.200	0.711	470		
2"	2.375	1.913	0.218	0.984	400		
2-1/2"	2.875	2.290	0.276	1.500	420		
3"	3.500	2.864	0.300	2.010	370		
3-1/2"	4.000	3.326	0.318	2.452	350		
4"	4.500	3.786	0.337	2.938	320		

Table 3. Materials needed to build SIM PVC pump

Materials to make a DN40 sanitary manual pump.

Depth of well (m) **10**

Item	Size	Type	Supplier	Length	Price	Price /m or ea.	QTY	Subt. (Bs)	Note
Tubo PVC	DN25	SCHED40	DISMAT	6	53	8.8	1.25	11.04	Handle and valve bodies.
Tubo PVC	DN50	Sanitary	DISMAT	4	32.2	8.1	1	8.05	Entry tube.
Tubo PVC	DN40	Sanitary	DISMAT	4	20	5.0	10.5	52.50	**Cylinder (500mm + depth of well)**
Tubo PVC	DN20	SDR21	DISMAT	6	23	3.8	11	42.17	**Piston (1 metre + depth of well)**
Pegamento (125ml)	-	-	DISMAT	na	25	25.0	0.25	6.25	Quarter of a container.
Limpiador (60ml)	-	-	DISMAT	na	7	7.0	0.25	1.75	Quarter of a container.
Cachina	20mm	-	-	na	1	1.0	2	2.00	-
Te para pegar	DN20	-	-	na	2.7	2.7	1	2.70	Tap-stand
Codo para pegar	DN20	-	-	na	2.2	2.2	3	6.54	Tap-stand
Goma para el sello	5mm	-	-	na	5.0	5.0	1	5.00	Seal material (estimated)
Mangera de Goma	3/4 inch	-	-	na	4.0	4.0	2	8.00	-
Copla para pegar	DN25	-	-	na	3.02	3.0	1	3.02	Valve connector
Niple con rosca	DN20	-	IPS	na	1.7	1.7	2	3.36	Seat
Codo para pegar	DN25	-	-	na	3.8	3.8	1	3.79	Handle
Te para pegar	DN25	-	-	na	5.1	5.1	1	5.05	Handle
Tapon para pegar	DN25	-	-	na	3.0	3.0	1	3.00	Handle
Copla con rosca	DN20	-	-	na	3.1	3.1	1	3.09	Valve
Te con rosca	DN20	-	-	na	5.6	5.6	1	5.55	Seal retainer
Goma ancho (m)	-	-	-	na	2.0	2.0	1.5	3.00	Secure the entry tube to post (installation)
Goma delgado (m)	-	-	-	na	2.0	2.0	1.5	3.00	Secure pump in the entry tube (installation)
								178.9	Bolivianos
								25.55	$US

Note: The final price depends greatly on the depth of the well.

BACKGROUND RESEARCH CONCLUSION

The research compiled above is to be used as an aid to clarifying and setting goals and objectives for the SIM PVC hand pump project for this 2014-2015 senior design team. From this, basic understanding of the pump and material properties was gained, as well as direction for the tests to be performed this coming year. An understanding of the pump users' culture and climate is also gained, along with the pump's purpose, shaping the goals and steps the senior design team this year will take.

Project Goals and Objectives

The goal of this project is to improve accessibility to clean drinking water for communities in Bolivia by assessing and improving the performance of the SIM hand-pump design while maintaining easy assembly, maintenance, usability, and low cost for the people of Vacas.

To do this, the following seven goals have been identified:

- Complete longevity testing of various PVC hand pump designs/modifications.
    - Test to failure
    - Perform multiple longevity tests (increase measured data for calculating efficiencies, etc.)

- Optimize the performance and efficiency of at least three PVC design components during the academic calendar year.
    - Analyze the effects of curvature on the piston seal and other components.
        - Consider alternate materials for pump design (HDPE, PP, or PVC)
        - Develop a test method for analyzing the effects of curvature
        - Analyze the relationship of pump angle to overall cylinder curvature
        - Create an internal visual model of piston rod inside the cylinder
    - Analyze the wear and efficiency loss from silt and fine abrasives suspended in the water.
        - Design a machine to simulate wear on PVC
        - Consider a possible foot valve filter to prevent some abrasives from entering the pump
    - Analyze the piston seal performance by comparing the optimal pumping resistance to the pumping efficiency (work out vs work in).
        - Continue the development of seal designs
        - Determine and compare the efficiencies of seal designs

- Develop a field method of measuring the hand pump performance and efficiency for users of the pump.

    - Choose a method people in the field could hook up to the pump and collect real data. (flow rate, efficiencies, force)
    - Must be a compact easy to use method for data collection

- Refine the instrumentation on the existing apparatus, including implementing an Op Amp circuit to amplify the strain gauge force signal, to provide a more accurate measurement of the pump efficiency.
    - Design a circuit to give data on the pumping force by amplifying signals from strain gauges using a Wheatstone bridge and Op Amp.
    - Install a filtering system of debris in the water to yield more accurate flow and efficiency measurements.

- Improve the test apparatus support and fluidity of motion.
    - Add structural improvements to the testing apparatus
    - Improve the fluidity of pumping motion

- Publish online tools/calculators for adapting PVC pump components to new environments or component sizes.
    - Determine a platform for the program
    - Create necessary calculations
    - Repeat b to create a more comprehensive tool with more inputs and outputs

- Explore expanding the use of the PVC pump to new regions and/or new applications.
    - Explore high head (20m) conditions while maintaining a very low cost PVC pump design.
        - Determine modifications to current to pump design for high head conditions

- Explore adding a mechanism to the pump to introduce a mechanical advantage to make pumping easier

- Analyze the horsepower and torque for various methods of motorizing the PVC hand pump.

  - Explore demand for motorized pump, including the effect of cost

  - Explore possible motorizing options or alternative solutions

Of these objectives, several are noted as priority because they must be completed before others, or they give critical information. Objective 4, improving instrumentation, is critical to give better data so that Objective 1, longevity testing, can be carried out, which is also critical. Objective 5 is critical as it contributes greatly to the ability to test well. Objective 2 is critical because it analyzes the performance of the pump, including issues noted in Bolivia.

However, objectives 3, 6, and 7, are also important and will yield valuable information as they pertain to aiding the field use of the pump in Bolivia and other locations possibly. These objectives can allow for great expansion of the use and adaptability of this pump design.

This project will require engineering skills from several areas. This includes knowledge from classes such as Fluid Mechanics, Mechanical Design, Kinematics, Dynamics, Properties of Engineering Materials, Contemporary Manufacturing, Electrical Machinery, Circuits and Instrumentation, and Engineering Graphics. Knowledge of the materials being used, especially plastic piping, will be critical, as well as knowledge of data collection and instrumentation systems. Finally, knowledge of the climate and culture of Bolivia is critical to complete this project for its stated purpose of aiding the Bolivian people.

Project Specifications and Constraints

1: For the existing PVC pumps, the head capability must be at least 10m. They must have a discharge flow rate of no less than 1 liter per minute at an average pumping speed (1.2 pump cycles/s) Pump must be able to run at least 60,000 cycles, or 100 liters/day for 600 days before failure (the point where it can no longer function properly) Its piping and other parts must be made from cheap and easily obtainable materials in Bolivia. The manufacturing process must be done with simple tools and techniques and the pump must be easily maintainable by trained Bolivians. The force required must not exceed 7-10 lbs (the amount of force a small child can provide).

2-a: The theory of the pump curvature effecting the pumping for a PVC seal - PVC pipe cylinder must be either proven or disproven. To prove that the theory is correct analytical or physical model evidence of the pump must verify that the flexing/bending of the pipe reduces the overall effectiveness of the pump (either force or fluid flow), or an alternate theory must be established discussing the reduction in effectiveness of a PVC pipe-PVC seal cylinder combination. Based on the theory testing should be conducted for the curvature of the pump. Testing of the curvature should be capable of measuring both internal piston rod and external cylinder flexing as well as seal to cylinder component interaction.

2-b: The wear machine must be designed and built in order that it may run the pump in a vertical direction as well a horizontal plan. The wear machine must be able to fit within a room 10’x10’x9’. It must be able to run unattended and capable of achieving a minimum of 60,000 cycles, which is equivalent to the designed life span of the pump by SIM. The machine must have a means by which it is capable of independently record the number of cycles it has run. A foot valve filter will also be designed in a continued effort to decrease wear within the pump. This filter must be able to be built with materials found in Bolivia and must be capable of keeping any particles with a diameter of 0.5cm or larger from passing into the pump.

2-c: The final chosen seal design must be simple to manufacture, resistant to wear and require minimal force to operate. This design must be able to be manufactured within a timeframe of 5 hours. The material must show no visible signs of material loss or damage after completing 60,000 pumping cycles and the force required to operate the pump at a head of 30ft must be less than 10 lb.

3: A preliminary field method should be established for testing SIM’s PVC hand pumps in Bolivia. The preliminary field method will be considered successful if it is capable of measuring the force and fluid flow of a pump, and if the testing is able to be done by either a Bolivian local or an SIM representative.

4-a: The voltage output from the op amp must give a readable output signal, but not large enough to exceed 3.3 V, the maximum voltage the Arduino can receive (2013-2014 Senior Design report).

4-b: The debris catching device must be before the flow meter and prevent debris from catching in the mesh of the flow meter. However, it must also not block the flow through the piping attached to the apparatus. It must allow the flow meter to be full of fluid at all times, and be far enough away from the flow meter to not disturb the normal water flow.

5-a: Overall, apparatus modifications should be performed in such a way that they do not disrupt the longevity testing schedule. Modifications to the apparatus joints should result in at least a 50% reduction in play.

5-b: The method used to document the pumping motion will need to provide numerical data. If an Arduino-based accelerometer is chosen, it should be compatible with the existing hardware. Based off of this data, modifications to the motion should be attempted if it deviates by more than 15% from the motion generated by normal use. Modifications will be deemed successful if the changes show a reduction in motion deviation.

6: The first version of the design computation tool will be in an Excel platform. The second version will be a web-based app. In the Excel platform, the equations will be able to be modified if needed and more flexible to suit the higher-knowledge user. The web-based version will be more applicable for use with people who might not have the background engineering knowledge. Regardless, the inputs will consist of pump dimensions, water depth range, and well depth. The outputs will be required pump force and water flow-rate. If the program is modified to include an even more comprehensive input and output, those modifications will improve the design usage for missionaries.

7-a: The head capability of the motorized pump must be at least 10 m. The motor will need protection because of the water hazard. As with the standard pumps, it must be able to run at least 60,000 cycles, or 100 liters/day for 600 days, before failure. (the point where it can no longer function properly) The cost for one of these motorized pumps should be around $300* or less.*Purchase price limit is currently unknown because some communities may be willing to put their money together to purchase a higher quality pump.

7-b: The pump head capability for the higher head pump must be at least 20 m. Its cost should be kept below $100. If the design for this pump is hand operated, the force required must be identical or less than that of the original design. Currently, this means that it must be operable by the amount of force a child can produce (approximately 7 - 10 lbs). Also, one of the limiting factors is piper and material availability in Bolivia.

Project Plan

The project plan is broken down for all 7 objectives and sub-objectives that the team plans to accomplish during the academic year. For each objective the major tasks that need to be accomplished are outlined and necessary resources are identified. At the end of this section there is a Gannt chart showing an approximate timetable and the “critical path” is identified.

1. The first phase of Objective 1 is to fabricate additional pumps for testing. In this phase, it will take approximately 20 hours per pump fabrication and depending on the number of additional pumps fabricated, may require additional resources that could include PVC pipe, tire rubber, and marbles.

Phase 2 is to continue longevity testing of the previous design and complete the testing to failure. During this phase, data for force applied to the handle and flow rate will be measured and

evaluated. Before phase 2 can be initiated, the instrumentation on the apparatus must be refined for more accurate data measurement. This means Objective 4 must be complete before phase 2 begins. It is unsure how long this phase will take, as a pump has not yet reached failure at such a high number of cycles.
Phase 3 of Objective 1 is to perform longevity testing of the new seal design which will also include recording and evaluating performance data during the testing. Since we will likely remain with a single testing apparatus, this phase cannot be initiated until phase 2 is complete. It is also unsure how long this phase will take, as this will be the first longevity testing of the new seal design. If phase 2 is not yet complete by January, we will initiate phase 3, as data for the new pump design is a high priority for comparison. Otherwise we will initiate phase 3 as soon as phase 2 is complete.

2. In order to quantify the performance and efficiency of at least three PVC design components during the academic calendar year, our team has identified three sub-objectives to complete the major task. These sub-objectives are outlined below.

2-a. Analyze the effects of curvature on the piston seal and cylinder, and address any issues related to pump performance.

For this sub-objective the team members will initially prove the theory that the pump curvature impacts pump performance and the required pumping force. To do this in the early stages of the project a visual internal model of the flexing piston rod and cylinder shall be produced. A test method to show the effects of bending and flexing of the cylinder and the internal piston rod should be established by the end of November, and if the method is established earlier preliminary testing shall be conducted. During the second semester preliminary testing shall be conducted for this sub-objective. Midway through the second semester preliminary data analysis shall be conducted to show the relationship of pump performance to the pump angle and the cylinder curvature. At this time an engineering decision shall be done to determine whether changes to the design should be made. Final testing and analysis should all be completed by the second week of April.

2-b. Analyze wear and efficiency loss from silt and fine abrasives suspended in water.

To accomplish this sub-objective we will design and build our own machine to simulate the wear experienced by the PVC pumps while in use in Bolivia from suspended abrasives that may be in the water. This machine should be fully designed, built and operational by the end of November. This will allow for testing of various pump components to begin by the start of the second semester. Holding to this time frame will allow the machine to function throughout the spring semester as a means to continually test potential changes or new components we wish to add to the pump design. Having this capability will help to add to the robustness of any design or material changes.

2-c. Create a functioning foot-valve filter that will help to limit the amount of foreign material entering the pump and help to prevent pump clogging.

To accomplish this sub-objective designing and testing a functioning filter for the foot-valve of the pump must be created with materials available in Bolivia. This filter will help serve to prevent foreign material from entering the pump and damaging the pump or decreasing the efficiency. A final design should be finished by the end of the fall semester and then thoroughly tested by March of the spring semester. This will leave all of March and April to make any necessary changes to the selected filter design.

2-d. Continued development of a more efficient and manufacturable seal design

This sub-objective will be accomplished by continuing off of last year's senior design team's findings and continuing to develop new and better methods of creating the piston seal. Currently the proposed new seal design is a PVC seal and therefore further testing and development will be done on this design. Further trial of new innovative designs and use of materials will be continued. By the end of fall semester we will have at least two new or improved seals that then will be further tested throughout the spring semester. The final seal design should be selected no later than the beginning of April.

3.To develop a field method of measuring the PVC hand pump performance and efficiency for users of the pump will be a second semester objective. At least one preliminary method should be established by the middle of February. Preliminary testing and analysis of a preliminary method should be completed by the start of April.

4-a. The first sub-objective of objective 4 is to improve the instrumentation to measure pumping force. So, a circuit will be designed to give data on the pumping force by amplifying signals from strain gauges installed on the apparatus handles (which is attached to the pump), using a Wheatstone bridge and Op Amp.

In this first sub-objective, sizes must be selected for circuit components based on the strain gauge signal output and desired input voltage into the Arduino microcontroller. The final design of the circuit (i.e. component sizes) can be completed and materials ordered within two to three days. Once the materials arrive, the strain gauges and circuit can be implemented and calibrated, within twelve to fourteen days after ordering. Once the circuit is calibrated, with the offset being subtracted by the Arduino system, this instrumentation should be ready for use in testing.

4-b. The second sub-objective of objective 4 is to improve performance of the flow meter to give better efficiency measurements. To do this we will install a filtering system to catch debris in the water before they reach the flow meter.

To accomplish this sub-objective, a final design will need to be chosen, potentially involving a mesh to direct debris into the expansion tank, with the flow then continuing to the flow meter. This can be completed within one to two days. From there, materials can be obtained in one to two days, most of which can come from existing team materials or can be printed on the 3D printer. Finally, the design can be implemented on the apparatus and the operation tested, within one to three days.

5. To achieve these goals, first the current state of the apparatus will be evaluated and the pumping motion documented to determine potential areas of improvement. If needed, additional documentation of the realistic pumping cycle will be conducted. These results will be compared to the motion produced by the testing apparatus. Based off of these findings, areas for improvement will be chosen and possible solutions developed. Basic modifications of the pump will be completed by the end of the first semester, and all other modifications will take place during the second semester. Finally modifications will be implemented and the results documented.

6. To publish online tools/calculators for adapting PVC pump components to new environments or component sizes there are four phases that need to be completed. During phase 1 a platform for the program should be determined that will be created during the second semester. This will require the research of different platforms including online options followed by an engineering decision to determine the best overall tool. The estimated time to accomplish this is approximately 3 weeks. The second phase of this objective is to create and determine the necessary calculations, which includes deciding upon inputs and outputs as well as incorporating associated formulas and calculations. Completing phase 2 of the project is estimated to take around three months. During the third phase the online platform will be created and tested to verify its functionality. The third phase will take all of the second semester.

7-a. The primary task is to develop a design which incorporates a single-phase motor as its primary power component. This will involve extensive communication with Dale Harlan. In his email, Dale said that most cheap, general service electric motors can be found in Bolivia. The initial task of this objective will be to do a small amount of research on the motors that are available in the US, then contacting Dale with the findings. Dale might be able to find a similar motor down in Bolivia, which could be used on the actual pumps that are made in Bolivia. By the end of the first semester, a specific motor should be chosen for our design and a preliminary design should be made which incorporates the motor into the PVC pump. Granted, the motor will be chosen sooner than the preliminary design is completed. As far as the design itself is concerned, attaching a flywheel or pump jack counterweight apparatus to the motor should help transfer power from the motor to the pump and therefore could be a good option.

Before proceeding to the Test and Evaluation plan, the motor must first be proven to deliver enough torque for the 10m head limit imposed in the Specifications. During the first few months of the second semester initial testing should be conducted, and based off of the testing an engineering decision should be made to continue testing or support the other team functions.

7-b. In order to handle a higher head a few different options are considered. A preliminary design should be selected by the end of the first semester. Then like the previous sub-objective after a few weeks of testing during the second semester an engineering decision should be made as to whether the testing should be continued or if it should end. Although it is possible that constructing a motorized pump may become a viable option for achieving a higher head capacity for the pump, right now two different angles of attack for achieving higher head are considered. One idea is to construct some type of lever arm. A well-designed lever arm would be capable of doubling or perhaps tripling the amount of force a human can apply to the pump handle. Because the existing pump has not been subject to this size of a force before, testing needs to be done in order to see if our pump can withstand this. In order to simulate the higher pressure environment a deeper well would possess, the Senior Design team from last year used a check valve with weights placed directly on top of it, which the water would have to lift in order to flow. This method may prove to be the most effective, or other options may be considered.

The other idea is to create a similar pump, only with a thinner pipe. This would allow less water to be lifted at once, and thus, the force necessary to pump the water would decrease. Since one of the necessary components for this includes a thinner pipe that is consistently found in Bolivia, research needs to be done in order to determine the possibilities of this design.

Considering SIM has already started work on the smaller scale pump, this solution will be pursued first. This idea will be pursued by experimenting with different sizes of pipe, and building a full-scale model of a new pump. The pipe sizing calculation that shows what type of Bolivian pipe is needed for this is shown below.

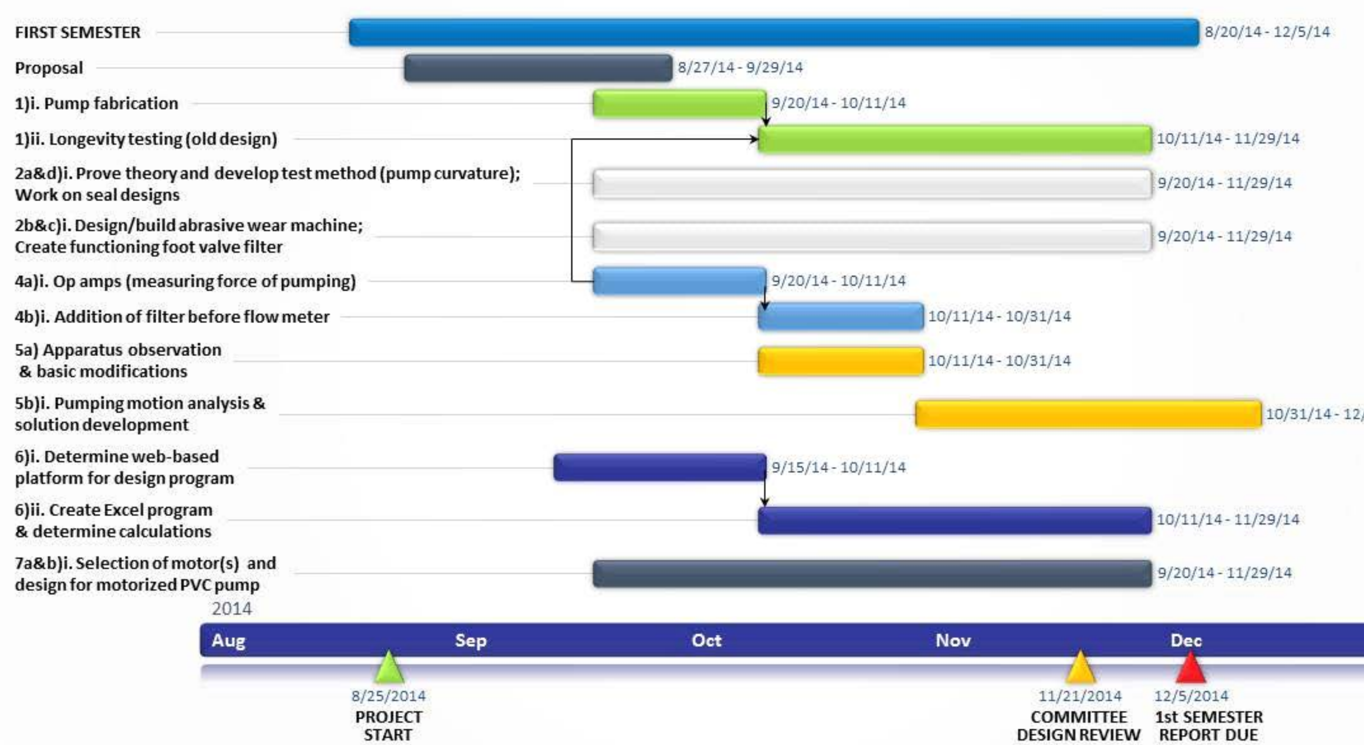
> The inner diameter of the current pump design is 37.8 mm. Calculate a new pipe diameter to use for the 20 meters of head design.
>
> For example, at 12 meters (current maximum depth according to World Health Organization):
>
> In order to achieve an identical volume of water and therefore an identical weight/force needed from the user, a pump with a pipe of diameter of the size calculated in this set of equations is necessary.

The percentage decrease in diameter of the old and new pipe is:

The only pipe sizes that are close to this, which are also available in Bolivia, are Schedule 40, 1’’ and 1-1/4‘’ nominal diameters, which have inside diameters of 1.029’’ and 1.360’’.

If for some reason the smaller scale pump solution is not sufficient, or an alternate design is desired, design and experimentation on the lever arm solution may begin. It must be proven that the current pump can withstand the force necessary to lift 20m head of water before this design can begin. Developing a design for this may be done without first acquiring data on what materials are available in Bolivia (a lever arm is a simple structure that could be made with many different materials. A time frame for this solution is dependent upon many factors that are yet to be determined.

The following pages show our teams projected timeline using a Gannt chart for each semester. The critical path will be in the creation of and testing of the PVC pump through longevity testing. The other objectives will be in support of the critical path or serve to address other needs of the Bolivian people.


FIRST SEMESTER
8/20/14 - 12/5/14
Proposal
8/27/14 - 9/29/14
1)i. Pump fabrication
9/20/14 - 10/11/14
1)ii. Longevity testing (old design)
10/11/14 - 11/29/14
2a&d)i. Prove theory and develop test method (pump curvature); Work on seal designs
9/20/14 - 11/29/14
2b&c)i. Design/build abrasive wear machine; Create functioning foot valve filter
9/20/14 - 11/29/14
4a)i. Op amps (measuring force of pumping)
9/20/14 - 10/11/14
4b)i. Addition of filter before flow meter
10/11/14 - 10/31/14
5a) Apparatus observation & basic modifications
10/11/14 - 10/31/14
5b)i. Pumping motion analysis & solution development
6)i. Determine web-based platform for design program
9/15/14 - 10/11/14
6)ii. Create Excel program & determine calculations
10/11/14 - 11/29/14
7a&b)i. Selection of motor(s) and design for motorized PVC pump
9/20/14 - 11/29/14
2014
Aug
Sep
Oct
Nov
Dec
8/25/2014
PROJECT START
11/21/2014
COMMITTEE DESIGN REVIEW
12/5/2014
1st SEMESTER REPORT DUE

Test and Evaluation Plan

The test and evaluation plan is broken down for each objective. In this section plans to test and determine satisfactory completion of the project are outlined.

1. A very similar plan that is previously stated for the pump design. The only difference is that once the testing and evaluation plan for the previous pump design is complete, we will perform identical testing and evaluation to the new pump design in order to compare the designs.

2. Testing of individual pump components will focus on the pump curvature, piston seal, and PVC abrasive wear properties.

2-a. The model should accurately reflect the internal interaction between the piston rod and the cylinder. The pump curvature data should be analyzed to show the relationship of pump performance to the pump angle and the cylinder curvature. In order to quantify the pump performance at various angles the testing should show comparative data of the pump's performance at various degrees of various seal designs. The performance or efficiency data of the pump should also show the required force required to push the pump. This is an important part of the testing because the users have a limited force that they are able to apply to pump the water. Once preliminary data has been collected an evaluation based on performance, efficiencies, and the manufacturability of the different options will determine the corrective action that should be made or whether the design should remain the same.

2-b. A machine will be developed to run various abrasive materials through the pump this will allow for simulation of foreign abrasive materials that may be in the water such as sand, silt and gravel. This machine will be able to run automatically to see how the materials will wear over long periods cycling and therefore will require the use of a motor. This machine will allow us to vary the level and type of abrasive material being pumped, and by looking at changes in component mass we can then evaluate the amount of wear to the material. Surface finish will also be analyzed after testing to further determine any wear on the components that over time could cause a loss in efficiency or a pump to fail. For further evaluating the efficiency loss due to wear, we will test a pump's volume flow rate with a flowmeter before and after being run through the wear machine. This machine will allow for improved robustness of our current design and future changes to components or materials.

2-c. We will develop a filter for the foot valve that can be run through longevity tests and the wear test machine, to and evaluate its ability to remain free from clogs (or obstructing the flow of water into the pump) and properly filter the water entering the pump. Collecting samples of water pumped and passing them through commercial grade filters to collect any particles that have made it past the foot valve filter will allow for an easy visual confirmation of a filter's performance.

2-d. We will continue to develop and design improved methods for creating a piston seal. We will further test the PVC seal that was found to be successful for last year's senior design team and continue to build on their research to develop new designs and potentially utilize new materials to create the most effective and efficient seal. We will test and analyze piston seal designs in several ways. First we will measure the force required to pump the piston. This measured force will provide information as to the friction created by the cylinder and seal that must be overcome. We desire the least amount of work possible to operate the piston with as much output as possible. A vacuum gauge will also be utilized to measure between each design the ability of each piston seal to create the vacuum we need for pumping. We will also utilize the wear machine to test piston seal designs ability to resist wear. Finally the piston seals will also be tested at various pump angles to ensure that we can maintain an efficient seal (work input/ work out) regardless of precise pump installation. The final design will be decided on the basis of efficiency and manufacturability.

3. The primary goal of developing the field method for measuring the PVC hand pump performance and efficiency is for the purpose of data analysis and secondly for maintenance need. Through data analysis either our team or future engineers will get real performance and efficiency readings from the end user. After a baseline has been established via pump performance and efficiency data the users may compare their performance and efficiency

readings. In order to meet the objective our team must establish the method and begin collecting data to be used as the baseline. The method should provide a means of measuring the required force to pump the water and a volumetric reading. After the baseline has been established if the readings are not similar then some type of check-up and/or maintenance will need to be done to the pump. There is also an aspect of providing SIM and/or the senior design teams with the data so that we can track pump performance/improvement over time for all the pumps not just individual ones.

4. To ensure that the strain gauge/op amp circuit is performing as expected, first the offset will be subtracted from the readings. Then known forces will be applied to the pump and the corresponding voltage values will be recorded and plotted against the force values. This will be similar to the calibration performed by the senior design team from 2013-2014 (see page 83 of the report). The same forces can be tested multiple times to ensure that the same voltage value is given each time. Finally, a test run with the pump will be performed to ensure that the strain gauge circuit is able to perform under repeated loading. If the circuit for force measurement does not perform as expected, the gain can be increased to give a stronger signal to the Arduino, or the strain gauges can be placed in a different location on the apparatus or pump, with special considerations for canceling un-wanted strain data.

To ensure that the flow filter is working correctly, a test run with the pump will be performed in which flow data is measured, and debris is checked for after the test. The test will be successful if the flow meter gives the expected flow results and the pipe is not clogged. If the debris appears to be clogging the pipe, additional actions can be taken by installing a larger area for the debris to be channeled into.

5. Improve the test apparatus support and fluidity of motion to match the realistic pumping cycle more closely.

5-a. Structural improvements to the testing apparatus

The structural improvements will focus on the member joints, bearings, and metal frame. Measurements of the pin joints will be taken to determine gap sizes. The condition of bearings will be noted to determine if they will need to be replaced. Video will be used to document the structural integrity of the metal frame while the apparatus is in operation. After modifications are made, similar documentation will be used to evaluate the effectiveness of the changes.

5-b. Improving fluidity of pumping motion

Video documentation will be used to evaluate the current motion of the test apparatus. Since there is already video of the pump being used by the Bolivians and members of the team last year, additional video documentation of realistic pumping will only be conducted if deemed necessary. If numerical data is desired, testing methods to track velocity and acceleration throughout the pumping cycle will be developed. After investigating the differences between the pumping motion, modifications will be made to the motor velocity control or flywheel to create a better simulation. Similar testing will be conducted to evaluate the effectiveness of any modifications.

6. The calculator tool will need to be tested and evaluated to ensure that it works well. This will take approximately 120 man hours. The testing will include trying out the program here as well as getting the SIM team to check it out. It will also be helpful to get advice from computer engineering and computer science majors here at the university. Further evaluation will be done after each change to make sure it continues to run smoothly.

7-a. If the motor does not deliver enough torque, it may be necessary to pursue producing a design that merely provides assistance to hand pumping. Other options include: developing a more efficient design to produce more force while potentially sacrificing output rate, or changing the pipe sizes. An engineering decision will be made to continue pursuing this option if it proves to be a highly impactful project for the Bolivian people.

If the motor is found to deliver enough torque, a lifetime test should be conducted. This would prove whether the design is sturdy/rigid enough for use in Bolivia. The goal for this is 60,000 cycles. If this goal is not met, once again, the other options will be considered.

7-b. A pump strength test needs to be conducted to see if the pump parts can withstand the added weight of 10m of head. After a lever design is chosen, extensive further testing optimization could be done for it.
The first test that needs to be completed is a force measurement to determine if our design is taking a similar amount of force to pump as our original design. When the force is satisfactory testing and evaluation testing and evaluation will be performed including a 60,000 cycle test to determine if the new design will withstand repeated use.

Resource Requirements
This project will be divided into seven objectives of which each team member will lead. Within the team however, members will also assist in objectives other than their own primary objective.

OBJECTIVE 1

- Material Costs
    - PVC - $75
    - Miscellaneous: marbles, tools, etc. - $40

Man hours:

- 40 for phase 1
- 120 total hours for phase 2 and 3 combined (net 160 hours)

Space – EPL office using hacksaw, small torch, vise and nails
Testing site water well, truck for transportation of testing apparatus

OBJECTIVE 2

2-a. Material Costs

- PVC – $50
- Angle measurement device(s) - $50.

Man hours

- Perform testing - 40 hours
- Research -5 hours
- Optimization - 40 hours

2-b. Material Costs

i. Clear plastic tub or tank - $20
ii. Motor and components - $150

- PVC - $50

Man hours

- building- 100 hours

ii. Testing- 40 hours

2-c. Material Costs

i. PVC - $20
ii. Chicken wire - $15

- Miscellaneous material for testing - $30
- Commercial water filters - $50

Man Hours: - 80 hours

- Testing – 40 hours

2-d. Material Costs

i. PVC- $50
ii. Hardware - $25
iii. Sand paper - $30

- Rubber Hose - $15
- Vacuum Gauge - $100

Man hours – 100 Hours

- Testing – 30 Hours

OBJECTIVE 3

3. Material Costs

i. Force measurement device(s) - $100

ii. Flow rate device(s) - $50

Man hours

- Perform testing – 40 hours
- Research – 5 hours
- Optimization – 20 hours

OBJECTIVE 4

4-a. Material Costs

- Op Amp(s) - $10
- Resistors - $15
- Strain gauges - $150
- Arduino boards - $60
- Laptop – possibly borrow

Man hours

- Final Research/Design: 3-7 hours
- Implementation: 4-8 hours
- Calibration: 2-7 hours

4-b. Material Costs for Flow Meter Protection

i. Small PVC components - $10

ii. Mesh – from 3D printer

Man hours

- Final Research/Design: 3-8 hours
- Implementation: 5-10 hours
- Testing of Performance/Modification: 10-12 hours

OBJECTIVE 5

5-a. Material Costs for structural improvements

- Bearings $50
- Plastic bushings $15
- Or if 3D printed, $5

Man hours

- Initial testing one week (10 hours)
- Purchase and construction three weeks (40 hours)
- Final testing one week (10 hours)

5-b. Material Costs for improving pumping motion

i. Materials $60

Man hours

- Initial testing two weeks (20 hours)
- Design and construction four weeks (60 hours)
- Additional testing two weeks (25 hours)

OBJECTIVE 6

Material Costs

- Publish webpage to a website not through Cedarville = $250
- Book Resources to buy on Amazon = $200

OBJECTIVE 7

7-a. Material Costs

- Motor(s) - $300
- Miscellaneous (pump jack, flywheel) - $100

Man hours

- Research – 20 hours
- Developing design – 100 hours
- Optimization – 150 hours

7-b. Material Costs

- PVC pipe - $50
- Miscellaneous (material for lever arm, etc.) - $100

Man hours

- Research – 20 hours
- Initial designs for both concepts – 150 hours
- Optimization of chosen – 150 hours

The total resources required for this design project by objective are estimated below in Table 4. Although the total man hours for this project will satisfy the design project requirements, each individual objective may require more or less man hours than required for one member. However, since all team members are assisting in objectives outside of their own, the man hours required per team member should become equal.

Depending on the objective in this project, there will likely be minimal time spent in the shop. Due to the goal and purpose of this project, much of the fabrication and testing of the hand pumps can take place either in the assigned senior design space, or at the shallow well for testing. Most time spent in the shop will be for the purpose of preparing or improving the testing equipment, while the tests themselves will not likely require shop space. During fabrication of the pumps, good ventilation will be required as Bunsen burners will be used to manipulate the PVC pipes and can give off harmful chemicals in the air.

Table 4 – Human Resource Requirements for PVC Hand Pump Project

Objective	Project Need	Man Hours
1	Phase 1- PVC hand pump fabrication	40
	Phase 2- Previous design longevity testing	40
	Phase 3- New design longevity testing	80
2	a. Perform testing	40
	a. Research	5
	a. Optimization	40
	b. Building	100
	b. Testing	40
	c.	80
	c. testing	40
	d.	100
	d. testing	30
3	Perform testing	40
	Research	5
	Optimization	20
4	a. Final research/design	7
	a. Implementation	8
	a. Calibration	7
	b. Final research/design	8
	b. Implementation	10
	b. Testing and performance/modification	12
5	a. Initial testing	10
	a. Purchase and construction	40
	a. Final testing	10
	b. Initial testing	20
	b. Design and construction	60
	b. Additional testing	25
6	Determine platform for program	10
	Create necessary calculations	40
	Test calculator	10
	Improve tools	60
7	a. Research	20
	a. Developing design	100
	a. Optimization	150
	b. Research	20
	b. Initial designs for both concepts	150
	b. Optimization of chosen	150
	Total Man Hours Required	1627

The total material costs for this project is outlined in Table 5 below.

Table 5 – Material Costs Required for the Project

Objective	Project Need	Budget (US $)
1	PVC	75
	Miscelaneous parts: marbles, tire rubber, tools	40
	Angle measurement devices	50
	Clear plastic tub or tank	20
	Motor and components	150
	PVC	170
	Chicken wire	15
	Miscelaneous material for testing	30
	Commercial water filters	50
	Hardware	25
	Sand paper	30
	Rubber hose	15
	Vacuum gauge	100
3	Force measurement devices	100
	Flow rate devices	50
4	Op amps	10
	Resistors	15
	Strain gauges	150
	Arduino boards	60
	Small PVC components	10
5	Bearings	50
	Plastic bushings	15
	Miscellaneous for improving pumping motion	60
6	Publish webpage	250
	Book resources	200
7	Motor	300
	Miscellaneous (pump jack, flywheel)	100
	PVC	50
	Miscellaneous (material for lever arm, etc.)	100
	Total Budget Required	2290

Summary

The aim our the 2014-2015 Senior Design Project is to aid SIM in bringing clean water to people in need with a reliable, easy-to-use, effective, and inexpensive PVC hand pump. The team will build off the work completed by the 2013-14 senior design team on this pump and look into expanding the way the pump can be used to bring clean water access to more people. In working on this project, it will be important to keep in mind the culture(s) in which this pump may be used, the people using it, and SIM's goals for this project to be self-led, self-propagating, and self-funded. With this in mind, the team seeks to complete full scale testing to study the lifetime behavior of the pump, and study issues related to the pump, such as seals and wear. To aid in this testing, the team also seeks to improve the testing apparatus. Finally, the team seeks to aid in expanding the use of the PVC pump with field tools and alterations to the pump design so that it may be applied in new areas and ways. In all of this, the team seeks to assist SIM in their work of bringing clean water and healthy changes to the people of Bolivia, and through this, to provide people with the opportunity to hear about the living water Jesus offers.

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Appendix A

This Senior Design Project will consist of both individual work and group work. An example of individual work might be researching flywheels on the internet in order to determine the best possible flywheel to add to the PVC pump apparatus. An example of group work might be building a new PVC pump for testing. The projected responsibilities for each individual team member are shown below in *Table A.* However, these responsibilities may vary slightly because of unanticipated challenges and other various unforeseen circumstances.

Table A. List of Designated Responsibilities for each Team Member

	Team Responsibilities
Tyler Griggs	Team 1 Leader
	Creation of a field method of measuring the PVC hand pump efficiency and performance
	Analysis of the effects of curvature on piston seal
	Project management of team objectives
	Research/design support of Tyler Baechtle's goals
Tyler Baechtle	Facilitate the research and development of improved pump piston seal design
	Development of an abrasive wear machine and research into the effects of abrasives on the pump
	Design, development and testing of a foot-valve filter
Ryan Frazier	Longevity testing of previous and new designs
	Fabricate additional needed pumps for testing
	Assist in refining instrumentation on apparatus
Jonnah Baker	Team 2 Leader
	Facilitate Op Amp Implementation for Testing Use
	Project Management of Pump Design Calculation Tool
Victoria	Improve apparatus instrumentation (op amp circuit & flow meter)

Shrum	Aid in full scale longevity testing of the PVC pump	
	Research higher head options for the PVC Pump	
Matt Lee	Research Motors and Develop Motorized Design	
	Apparatus Mechanical Improvements	
Kyle Nelson	Research Motors and Develop Motorized Design	
	Research and Implementation for Lever Arm and Downsized pump Ideas	

Appendix B

Following are the pertinent PVC Material Safety Data Sheets

Sanderson Pipe Corporation Sheets

PVC PIPE

SECTION I – Manufacturer's Name:

Sanderson Pipe Corporation
One Enterprise West
Sanderson, FL 32087
(904) 275-3289 Fax (904) 275-3247

SECTION II – Hazardous Ingredients

All ingredients are bound-up in the manufacturing process and are not expected to create any hazard in handling or use.

SECTION III – Physical Data

Boiling Point	**Melting Point**	**Specific Gravity (H2O=1)**
N/A	N/A	1.35-1.55
Solubility in Water	**% Volatile by Wt.**	**Vapor Density (Air + 1)**
Insoluble	N/A	N/A
Vapor Pressure	**pH**	**Particle Size**
N/A	N/A	N/A

Appearance and Odor
Rigid and no odor

SECTION IV- Fire and Explosion Hazard Data

Flash Point	**Ignition Temperature**	**Flammable Limits in Air**
Not applicable to Solid products	>730*F (>388*C)	(% by volume) Lower: N/A Upper: N/A

Extinguishing Media
Water. ABC dry chemical. AFFF. Protein type air foams. Carbon Dioxide may be ineffective on larger fires due to a lack of cooling capacity which may result in reignition.

Special Fire Fighting Procedures
Wear positive pressure self-contained breathing apparatus (SCBA). Personal not having

suitable respiratory protection must leave the area to prevent significant exposure to toxic combustion gases from any source. In enclosed or poorly ventilated areas, wear SCBA during clean-up immediately after a fire as well as during the attack phase of fire fighting operation.

Unusual Fire and Explosion Hazards

None known

SECTION V – Health Hazard Data

Threshold Limit Value

None established

Efforts of Overexposure

There are no significant health hazards from vinyl compound at ambient temperatures. Inhalation of decomposition or combustion products, especially hydrogen chloride, will cause irritation of the respiratory tract, eyes and skin. Depending on the severity of exposure, physiological response will be coughing, pain and inflammation. Individuals with bronchial asthma and other types of chronic obstruction respiratory diseases may develop bronchial spasms if exposure is prolonged.

Emergency and First Aid Procedures

If irritation persists from exposure to decomposition products, remove the affected individual from the area. Provide protection before reentry.

SECTION VI – Reactivity Data

Stability	**Hazardous Polymerization**
Stable	Will not occur

Hazardous Decomposition Products

CO, CO_2, hydrogen chloride and small amounts of benzene and aromatic and aliphatic hydrocarbons.

SECTION VII – Spill or Leak Procedure

Steps to be taken in case material is released or spilled

Material is inert. Place into container for reuse or disposal.

Waste Disposal Method

Disposal of waste in accordance with federal, state and local regulations. For waste disposal purposes these products are not defined or designated as hazardous by current provision of the Federal Conservation and Recovery Act (RCRA) 40CFR261.

SECTION VIII – Special Protection Information

Ventilation

Provide efficient exhaust at all operations creating fumes or vapor. Cutting or sawing, machining, heat welding, thermofolding and other operations involving heat sufficient to result in degradation should be examined to ensure adequate ventilation.

Respiratory Protection

Not normally required
-If overheating results in decomposition resulting in smoke or fumes NIOSH/MSHA approved combination high efficiency particulate filter with organic vapor cartridge can be used. Gross decomposition may require the use of a positive pressure self-contained breathing apparatus.

Protective Equipment

Wear safety glasses

SECTION IX – Special Precautions

Certain operations, such as the installation of piping systems, may require the use of solvent cements. The user must obtain and comply with all safety precautions recommended by solvent cement manufactures. Avoid continued or prolonged breathing vapors produced by overheating.

SECTION X – Transportation

For domestic transportation purposes, these products are not defined or designated as a hazardous material by the U.S. Department of Transportation under Title 49 of the Code of Federal Regulations, 1983 Edition.

DOT Proper Shipping Name:	Not Applicable
DOT Hazard Class:	Not Hazardous
DOT Label:	None Required
UN/NA Hazard Number:	Not Required

Users Responsibility

A bulletin such as this cannot be expected to cover all possible individual situations. As the user has the responsibility to provide a safe workplace, all aspects of an individual operation should be examined to determine if, or where, precautions, in addition to those described herein should be passed on to your customers or employees, as the case may be. Sanderson Pipe Corporation must rely on the user to utilize the information we have supplied to develop work practice guidelines and employee instructional programs for the individual operation.

Disclaimer of Liability

As the conditions or methods of users are beyond our control, we do not assume any responsibility and expressly disclaim and liability for any use of this material. Information contained herein is believed to be true and accurate but all statements or suggestions are made without warranty, expressed or implied, regarding accuracy of the information, the hazards connected with the use of the material or the responsibility of the user. The information used in this letter was compiled from other MSDS letters with similar products.

The Greenstreak Group, Inc. Sheets

LAST UPDATE 8/2/2011

1. PRODUCT AND COMPANY INDENTIFICATION

Company

The Greenstreak Group, Inc.
3400 Treecourt Industrial Blvd.
St. Louis, Mo. 63122

24 Hour Emergency Response Information
CHEMTREC: 800-424-9300

Product: Greenstreak Flexible PVC Resin
Greenstreak PEC MAT Resin

Molecular Formula:	C2H3Cl
Chemical Family:	Not applicable (mixture)
Synonyms:	chloroethylene homopolymer compound

2. COMPOSITION/ INFORMATION ON INGREDIENTS

Compound	Content (WT.%)	
Polyvinyl Chloride Polymer	45-80%	
Inert Fillers	0-40%	CACO3, talc, carbon black, TiO2, clay
Heat Stabilizers	3-10%	Organometallic compounds of barium and/or calcium- zinc
Plasticizer	0-60%	High molecular weight esters
Colorant	0-5%	Organic and inorganic colorants

3. HAZARDS IDENTIFICATION

Emergency Overview

If proper procedures for processing PVC compounds are not followed, processing vapors can be liberated at elevated temperatures. The presence of these vapors may result in exposure. Additionally, the composition of these vapors may vary widely according to the individual processing procedures and materials used. Processors must determine for themselves the appropriate equipment and procedures for their use.

Potential Health Effects

Primary routes of exposure:
Inhalation of processing emissions during periods of elevated temperature.

Eye:

Vapors emitted during processing involving elevated temperatures may cause eye irritation. Dust resulting from the handling of powder may be irritating to the eyes.

Skin Contact:
Vapors emitted during processing involving elevated temperatures may cause skin irritation. Dust resulting from the handling of powder may be irritating to the skin.

Skin Absorption:
This material is initially a dry solid peller or waterstop coil; no absorption is likely to occur in its initial form. Vapors emitted during processing involving elevated temperatures may absorb through the skin at low levels.

Ingestion:
Slightly toxic by ingestion. Dust may become airborne during handling, resulting in the potential for incidental ingestion. Vapors emitted during processing involving elevated temperature may be ingested at low levels. Adequate ventilation should be provided.

Inhalation:
Dust may become airborne during handling, resulting in potential inhalation exposure. Vapors emitted during processing involving elevated temperatures may be inhaled if not adequately ventilated.

Hazard Classification

Acute Effects:
Dust associated with the handling of PVC powder as well as vapors liberated from PVC compound at high temperatures may be irritating to the eyes, skin and respiratory tract if not adequately ventilated.

Chronic Effects:
Chronic exposure to vapors from heated or thermally decomposed plastics may cause an asthma-like syndrome due to the inhalation of processing vapors or fumes. The onset of irritation may be delayed for several hours. Vapors may accumulate within the facility during normal operating procedures that involve elevated temperatures. Exposure to these elevated concentrations, if not adequately ventilated, may have significant health effects.

Carcinogenic:
IARC has determined that there is inadequate evidence of carcinogenicity of a polyvinyl chloride in both animals and humans. The overall evaluation of polyvinyl chloride is Group 3, meaning that it is not classifiable as a carcinogen (IARC Vol. 19, 1979). Polyvinyl chloride is not listed as a carcinogen by OSHA, NIOSH, NTP, IARC or EPA.

Some additives used to make PVC compound may contain metals, which in some chemical forms are suspected or confirmed carcinogens. These metals, if present, are bound in the crystalline structure of the additive, and to the supplier’s best knowledge, do not present a significant health risk.

Additionally, the low levels of additives used in PVC compounds are also bound in the polymer matrix and to the best of the supplier's knowledge, do not present a significant health risk.

4. FIRST AID MEASURES

If inhaled:
Remove to fresh air. Obtain medical attention immediately if irritation persists.

If on skin:
Flush with water to remove material from skin. Obtain medical attention if irritation persists.

If in eyes:
Flush with large amounts of water for 15 minutes. Obtain medical attention if irritation persists.

If swallowed:
No effect expected. If large amounts are ingested, seek medical attention. Only induce vomiting at the instructions of a physician.

5. FIRE FIGHTING MEASURES

Flash Ignition Temperature:	>600F
Flammable Limits (% By Vol.):	
Lower Explosive Limit (LEL)	Not applicable
Upper Explosive Limit (UEL)	Not applicable
Autoignition Temperature:	Not applicable

Fire Fighting Procedures/ Fire Extinguishable Media:
Carbon dioxide or water.

Unusual Fire and Explosion Hazards:
PVC evolves hydrogen chloride, carbon monoxide, and other gases when burned. Exposure to combustion products may be fatal and should by avoided. PVC Compounds will not normally continue to burn after ignition without an external fire source. Do not allow fire fighting runoff water to enter streams, rivers or lakes. The water may collect HCl and other combustion products.

Fire- Fighting Equipment:
Wear full bunker gear including a positive pressure self- contained breathing apparatus in any closed space.

6. ACCIDENTAL RELEASE MEASURES

Protect People:

Remove unnecessary personnel from the release area.

Environmental Precautions:
Contain material to prevent contamination of the soil, surface water or ground water.

Cleanup:
Sweep or vacuum material and place in a disposal container. See Section 11.

7. HANDLING AND STORAGE

Handling
Use the proper personal protective equipment during handling. Minimize dust generation and accumulation. Use good housekeeping practices.

Storage
Store in a cool, dry, protected area from heat, sparks, and flame.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

All personal protective equipment should be selected in accordance with the hazard assessment required by 29 CFR 1910.132 (d).

Ventilation:
May be necessary to provide general and/or local ventilation to help maintain airborne concentrations below exposure guidelines. Local exhaust ventilation should comply with OSHA regulations and the American Conference of Industrial Hygienists, Industrial Ventilation – A Manual of Recommended Practice.

Respiratory protection:
For most conditions, no respiratory protection should be needed. However, if dust is produced during handling a NIOSH- approved air purifying filter respirator that meets the requirements of 29 CFR 1910.134 should be used. Full – face self- contained breathing apparatus may be needed when dealing with vapors from combustion respirators must be selected based on the airborne levels found in the workplace and must not exceed the working limits of the respirator.

Skin protection:
Skin protection meeting the requirements of 29 CFR 1910.132 may be needed. Under normal conditions, work clothing should be sufficient. Wash skin if contacted by PVC powder or pellets. Wash contaminated clothing before reusing. Gloves for thermal protection may be necessary when handling hot or molten compound.

Eye protection:
Safety Glasses Chemical goggles.

Exposure Guidelines:
No exposure limits have been established for this material. It is recommended that exposure be kept below limits for Nuisance Dust (PNOC):

OSHA-PEL:	15 mg/M^3 8hr- TWA (total dust) 5mg/M^3 8 hr- TWA (respirable)	ACGIH-TLV:	10 mg/M^3 8 hr-TWA (inhalable) 3 mg/M^3 8 hr-TWA (respirable)

The following materials may be present in this product, but are not anticipated to exceed exposure limits under normal conditions.

CHEMICAL	OSHA-PEL	ACGIH-TLV
Calcium Carbonate	15mg/M^3 8 hr-TWA (total dust) 5mg/M^3 8 hr-TWA (respirable)	10 mg/M^3 8hr-TWA
Carbon Black	3.5mg/M^3 8 hr-TWA	3.5mg/M^3 8 hr- TWA
Titanium Dioxide	15mg/M63 8 hr-TWA	10mg/M^3 8hr-TWA (total dust)
Hydrogen chloride	5ppm Ceiling	2ppm Ceiling

Additional hazardous constituents may be released during processing involving elevated temperatures. These constituents are dependent on processing conditions and should be verified by processor.

Under normal processing conditions, no occupational exposure to vinyl chloride monomer exceeding the established exposure limits for this material are anticipated. The OSHA-PEL for vinyl is 1ppm over an 8- hr TWA. The OSHA-STEL for vinyl chloride is 5ppm for any 15-minutes period.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Pellets of varying size, hardness, and color
Odor:	No distinct odor
Boiling Point:	Solid
Melting Point:	Varies
Solubility:	None
Specific Gravity (Water=1.0):	1.15-1.7
Vapor Density (Air=1.0):	Not applicable
Vapor Pressure:	Not applicable
PH:	Not applicable

10. STABILITY AND REACTIVITY

Stability:
Stable under normal conditions.

Polymerization:

Hazardous polymerization does not occur.

Hazardous Decomposition Products:
Overheating may cause thermal degradation of PVC compound. Fumes and vapors (including CO, CO2, and HCL) may be generated during this thermal degradation. Emissions are also possible during conditions, and may accumulate within an inadequately ventilated facility.

Incompatible Materials:
Do not allow this product to come in contact with acetal or acetal copolymers within the extruder or molding machine. At processing conditions, the two materials are mutually destructive and involve rapid degradation of the products. Equipment should be purged with acrylic, ABS, polystyrene, or other purge compound to avoid even trace amounts of this product and acetals from coming in contact with each other.

11. TOXICOLOGICAL INFORMATION

The following information on polyvinyl chloride is extracted from both the HSDB and NTP database.

Animal Toxicity

Orals:	Rat, Tdlo	210gm/kg
Inhalation:	Mouse, LC50	140mg/M^3/10M

TDlo= Lowest toxic dose in a given species by a given route of exposure.
LC50= Concentration that is lethal to 50% of a given species by a given route of exposure.
Rodents exposed to PVC by dietary or inhalation routes for 6 to 24 months have shown no significant toxicological effects.

While PVC is generally considered an inert polymer, exposure to PVC dust has been reported to cause lung changes in animals and humans, including decreased respiratory capacity and inflammation. However, exposure approaching the nuisance dust exposure limits are not anticipated to pose a significant health risk.

12. ECOLOGICAL INFORMATION

Environmental Fate:

Aquatic:	No data available
Biodegradation:	No subject to biodegradation

Ecotoxicity:
Based on the high molecular weight of this polymeric material, transport for this compound across biological membranes is unlikely. Accordingly, the probability of environmental toxicity

or bioaccumulation in organisms is remote. Due caution should be exercised to prevent the accidental release of this material to the environment.

13. DISPOSAL CONSIDERATIONS

Waste Management Information:
Do not dump into any sewers, on the ground, or into any body of water. Any disposal practice must be in compliance with local, state and federal laws and regulations (contact local or state environmental agency for specific rules). Waste characterization and compliance with applicable laws are the responsibility of the waste generator.

14. TRANSPORT INFORMATION

Proper Shipping Name	Polyvinyl Chloride
DOT Hazard Class	Non- hazardous
DOT Shipping I.D. NO.	None
PG	None
Labeling	None
RQ	N/A

15. REGULATORY INFORMATION

Regulatory information is not meant to be all- inclusive. It is the user's responsibility to ensure compliance with federal, state or provincial and local laws.

SARA Title III
Section 302 and 304 of the Act; Extremely Hazardous Substances (40 CFR 355)

Component	CAS No.	TPQ (lbs)	RQ(lbs)
None	N/A	N/A	N/A

Note: TPQ- Threshold Planning Quantity RQ- Reportable Quantity

Section 311 Hazard Categorization (40 CFR 370)

Acute	Chronic	Fire	Pressure	Reactive
Not listed				

Section 313 Toxic Chemicals (40 CFR 372.65)
This product contains the following EPCRA Section 313 chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act of 1986

Component	CAS No.	WT. %
Not listed		

CERCLA
Section 102 (a) Hazardous Substances (40 CFR 302.4)

Component	**CAS No.**	**WT. %**	**RQ (lbs)**
None	N/A	N/A	N/A

RCRA
This product, as supplied, is not a hazardous waste according to the USEPA's Toxicity Characteristic Leaching Procedure. Any physical or chemical modification of this product may change the TCLP test results.

TSCA
All components are listed on the TSCA inventory or are exempt.

Proposition 65
This product contains substances known to the state of California to cause cancer and/or reproductive toxicity.

Canadian Regulations
This product has been classified according the hazard criteria of the Canadian Controlled Products Regulations, Section 33 and the MSDS contains all information required by this regulation.

WHMIS Classification- Not a Controlled Product.

OSHA 29 CFR 1910.1017
This compound may contain trace levels (<.001%) of VCM. Under normal working conditions with adequate ventilation, neither the OSHA-PEL of 1ppm (8-hr TWA), nor the OSHA-STEL (5.0ppm) should be exceeded. The workplace should be monitored and if the level exceeds any of the PELs or action levels, refer to 29 CFR 1910.1017.

16. OTHER INFORMATION

IMPORTANT: The information and data herein are believed to be accurate and have been compiled from sources believed to be reliable. It is offered for your consideration, investigation and verification. Buyer assumes all risk of use, storage and handling of the product in compliance with applicable federal, state, and local laws and regulations. **GEORGIA GULF CHEMICALS AND VINYLS, LLC MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, CONCERNING THE ACCURACY OR COMPLETENESS OF THE INFORMATION AND DATA HEREIN.** Georgia Gulf Chemicals and Vinyls, LLC will not be liable for claims relating to any party's use of or reliance on information and data contained herein regardless of whether it is claimed that the information and data are inaccurate, incomplete or otherwise misleading. This information relates to the material designated and may not be valid for such material used in combination with any other materials nor in any process.