

PERUVIAN ANDES WATER PUMP TEAM



ME 478 Product Development
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1. Introduction

"The purpose of life is not to be happy, but to *matter*, to be productive, to be useful, to have it make some difference that you have lived at all." ~Leo Rosten

The quote by Leo Rosten truly captures the essence of every human being doing their part in helping others and making the life they have lived, worthwhile. Too long have humans been happy with just making a living and trying to get by, while not doing their part in helping and improving humanity. It is now time for students at Michigan State University to step up and finally do what we have been preparing to do, make a difference.

This semester, our group has been assigned the task of designing a system which delivers water from a river up to 500 feet for the purpose of irrigation in the Peruvian Andes. Before ideas can be generated to solve this issue, it is absolutely vital to truly understand and define this problem. In the pursuit of defining this problem, the region in question must first be thoroughly explored and understood. Huamachuco is located in the north highlands of Peru in an area more generally known as the Peruvian Andes. Its elevation is approximately 10124 feet above sea level but varies a great deal throughout the region, and the area itself consists of many people living in small valleys which survive on rainfall agriculture. Most of the people living in the district are farmers with farm lands as big as 30 acres. Because of the relatively high elevation, sunlight is remarkably abundant and causes the temperatures to not get too low. It does not rain too often in Huamachuco however when it rains, it pours. Heavy rain fall causes the reservoirs in the mountains to rejuvenate and irrigate the farm land below. Most of the farmers grow crop such as corn, wheat and potatoes. Huamachuco farms lack many

resources which are abundant in the American farms, resources such as animals, heavy machinery, fertilizer and water. The region has many valleys, which causes an abundant amount of wind as well.

Now that an understanding of the region has been developed, the pertinent information can now be used to better define the problem. It is a well known fact around the world that in order to obtain high crop yields per acre, regular irrigation must be practiced. Irrigation is defined as the watering of dry land by artificial means to foster and enhance plant growth. Since Huamachuco is located at a relatively high elevation of 10124 feet above sea level, water irrigation can be cumbersome. Sometimes the water is guided by use of ditches from reservoirs into the arable land, however not everyone in Huamachuco is fortunate enough to have these reservoirs at their disposal. With that being said, most of the farmers do have access to a ravine, the only problem is that this ravine is located rather far below their crops, sometimes as much as 500 feet.

Currently, the people of Huamachuco have no choice but to make the journey on feet from their lands to the ravine, fill buckets with water, walk back to their lands and continue with irrigation. As can be imagined, this is not the most efficient way of carrying water but the people in this rural area do not have any other choice at the moment. Huamachuco lacks the electrical infrastructure which many people around the world take for granted. Therefore using electric devices to carry the water is not a feasible option. Some animal labor is available to help with this chore, however if animals are used to carry water, the issue of feeding these animals arises. The people in the area itself are not the wealthiest, in fact they barely have enough supplies to feed their families. This is why the system which will need to be designed for this problem will

have to consider affordability in order to be marketable in the region. Most of the residents are not well educated but have enough knowledge to work with simple devices. After taking all of this important information into consideration, the following problem statement can finally be generated. The purpose of this project is to design a system which is capable of carrying water up to an elevation of 500 feet, is constructed out of low cost materials, requires low/no maintenance, is powered by sustainable/available energy, is easy to install, and pumps enough water for the purpose of irrigation.

2. Design Parameters

Generic Design Parameters when Developing a New Product

- | | |
|--------------------------------|----------------------------------|
| <i>1. Function/Performance</i> | 15. Size |
| <i>2. Product Cost</i> | 16. Weight |
| <i>3. Available Materials</i> | 17. Spatial Constraints |
| <i>4. Safety</i> | 18. Aesthetics |
| <i>5. Quality</i> | 19. Transportation and Packaging |
| <i>6. Reliability</i> | 20. Personnel |
| <i>7. Mechanical Loading</i> | 21. Noise Radiation |
| <i>8. Maintenance</i> | 22. Operating Instructions |
| <i>9. Service Life</i> | 23. Government Regulations |
| <i>10. Human Factors</i> | 24. Environmental Conditions |
| 11. Health Issues | 25. Operating Costs |
| 12. Quantity | 26. Shelf-life Storage |
| 13. Environmental Issues | 27. Delivery Date |
| 14. Energy Consumption | |

These 27 design parameters are ranked from most important to least important when considering our design. The top ten parameters are further examined, and an explanation is given as to why they carry more importance than the others. Some of the parameters can be disregarded or seen as negligible to the pump design. Each of the top ten design parameters are ranked from a scale of 0 to 5 as shown in table 1. The numbering scale is weighted with a five holding the most importance and zero holding the least importance. To design a product effectively, it is important to rank all the parameters in a descending order as well as weigh each top parameter numerically. By performing this exercise, you ensure that the design will be created at the most optimal standards.

Table 1. Top 10 Design Parameters Ranked by Weight of Importance

Parameters	Weighted Importance
1. Function/Performance	5
2. Product Cost	5
3. Available Materials	5
4. Safety	4
5. Quality	4
6. Reliability	4
7. Mechanical Loading	3
8. Maintenance	3
9. Service Life	2
10. Human Factors	2

i. Function/Performance

In any good design, the function and performance of the mechanism is of great importance. A design can have the best aesthetics, but if the overall product cannot function or complete the role it was designed for, it becomes worthless. For this project, a water pump must be designed which can pump water 500 ft from a river to a reservoir for crop irrigation. When designing a pump, smaller tolerances must be taken into

consideration since there will be a high pressure build-up. Ensuring that the product will complete the task it was designed to perform is the number one parameter on the list.

ii. Product Cost

Product cost is another design parameter that ranks relatively high on the list when making decisions for a new design. For this project, being able to both design and manufacture a simplistic pump at a low price is critical. Designing a functional pump should not be the hardest task at hand, but manufacturing a pump at a low price is. Our goal is to design a pump which the communities in the Peruvian Andes can both build themselves and afford to build. Product cost is always an important issue when analyzing the design specifications. In larger businesses, utilizing concurrent engineering can help reduce the product cost and achieve the set target cost that was established. In our situation, the group must take into consideration all the materials that are available to the Peruvian community and make certain that they can afford the necessities for manufacturing this design.

iii. Available Materials

This design parameter is especially important due to our goal of producing our product within the countries. If the materials we use are not readily available within those respective countries then we will be forced to ship our product overseas, causing a spike in prices and the goal of helping the people become dependent upon themselves. Or on the other hand if the materials are not available in the other countries it would force us to use resources that are specific to that nation. This would then vary from country to country. Cause significant design differences.

iv. *Safety*

Safety is a primary concern in the development of our product. We want to make sure to supply the people with not only a proven working model, but also one that will secure their safety so that they can continue to go about their daily work. To assure this we will have to eliminate most kinks or hazardous flaws in the design phase. It will be necessary to meet requirements of the EPA (Environmental Protection Agency) and the OSHA (Occupational Safety and Health Administration). As a whole, the feel of the group is that if we can meet the standards of the United States officials it will be safe enough for most countries. If we cannot work out all hazards we will make sure to present warning labels and instructions defining the proper way to use the product. We will use the safety checklist (table 7.2) located in the book Creative Engineering Design. Overall safety is an important design parameter; if we cannot build a safe product we cannot build an efficient product.

v. *Quality*

The overall goal of this project is to solve the problem defined, with our product we want to help the people receive a secure water source. Although this is true and we could solve this problem with many solutions. We want to make a quality product. We want to make a product that is affordable and reliable. To supply the people with a product that they will enjoy and want to use, satisfying their desire and solving their problem. To assure that this can be achieved, we will have to assure quality throughout the design and manufacturing stages making sure we do not stray away from the original plans and to not lose sight of the overall goal. A quality product means a happy customer.

vi. Reliability

In any product, reliability can be a big factor. Reliability is ensuring that the product that is designed, functions properly under prescribed operating conditions. With this project, the reliability of the pump is critical due to the fact it is supplying water for crop irrigation. If the pump proves unreliable, not only will the crops suffer, but the communities that eat and sell the crops. For any product to function reliably, every part must fulfill its specification. This is true for a space shuttle, an automobile, or even something as small as a water pump.

vii. Mechanical Loading

Mechanical loading is another design parameter that made our top ten priorities. Figuring out the different mechanical loadings a system can undergo is very critical in the design process. When further examining the pump and the specifications it must endure, mechanical loading becomes a big feature. Trying to pump water 500 ft would create a vast amount of head pressure on the pump, making the forces and loadings on the many different components very critical. When further analyzing this situation, we decided to break up the 500 ft and pump the water in smaller increments where it would be pumped to stations until it reached 500 ft. Even if the 500 ft is broken up into increments, the loadings on the pump need to be closely examined. Each component in the design can be analyzed for its durability and FEA studies may be performed in Uni-graphics to confirm the stresses being applied.

viii. Maintenance Protocols

Maintenance is important in giving the product a long lifespan. As a group it is important to specify what parts of the product need to be maintained and kept clean or greased, etc.

Although the goal of our group is not to have too much care for the product once it's in place, since the availability of things such as grease and materials may not be readily available. It is still important to outlay the specific things that need to be checked every so often, to assure nothing needs to be replaced or fixed. We will have a list of steps that will display how the product should be checked. A maintenance manual will be an important part of our product explaining how to use the product and what to recognize in the product if it's not working properly. Majority of maintenance will be performed by the customer therefore it is important for us to specify how to do these miniscule tasks to assure product life and satisfaction.

ix. Service Life

When designing any mechanism, ensuring the longevity of the product is very critical. This is true with any product that is trying to be sold or manufactured. The consumer wants a product that will work and last for an extended amount of time. Since the pump we are creating is used for water irrigation, making sure it lasts and needs little service is important. To market a product, most businesses promote their design by convincing the customer the service life is long. Other ways they attract the customer is adding a warranty to the product so if there is complications; a new product will be given to them free of charge.

x. Human Factors

Since our design ideas are reliable on human and product interaction, human factors becomes a viable design parameter. We will have to make sure first that the operator will be aware of how the product works and how to keep it working. We will have to analyze the group of people we are attempting to create this product for. We will have to take

into account the environment and how it can affect the operator while working with the product. We will also have to study the typical build and body of the user, to make sure that we can have a wide range of people able to operate the product. Overall with our product human factors becomes a crucial parameter within our design and operation stage.

3. State of the Art Evaluation of Current Solutions

Before a new solution can be implemented, solutions that are currently available must be evaluated to determine if constructing a new design is worth the effort. If a product, which is currently offered, is able to meet all the set specifications or requirements for a particular purpose, then it is not necessary for a new design to be developed. For example, let's assume that a task requires 10,500 lbs of rock to be moved 50 miles while giving 8 miles of travel per gallon of fuel and carrying 3 passengers. It would be a better use of time to conduct a quick evaluation of the current solutions and pick a product such as the 2007 Chevrolet Silverado Crew Cab. Without an evaluation of current solutions, there is a possibility of many resources being wasted on work that has already been done by others, and even if a solution is found, it is very likely to be sub-par when compared with the current model.

In order for a State of the Art Evaluation of current solutions to be carried out, a list of parameters, which will be used to assess different aspects of each solution, must be constructed. The following section of the report will take a closer look at multiple pump systems. These pump systems were chosen by the team because of their potential. Every system is capable of being efficient in all of the chosen parameters. Each system will be evaluated based on the set criteria list, and concluding remarks will be made at the end.

4. Power Sources

Generally speaking, any cost effective system must also be technically efficient. This means that a relatively high output is needed when compared to the input energy. This point applies to fossil fueled systems as well as alternative energy fueled systems. For alternative energies, the source, whether it is solar, wind, or water, is free however the in that case the capital cost of the system affects its overall efficiency the most. Therefore when talking about the overall efficiency, each component of the system needs to be analyzed separately and then brought together at the end. Power source is a component which can greatly increase or decrease the overall efficiency of any given system. All power sources need energy in one form or another, combustion engines need fuel, wind pumps need wind, Hydraulic Ram pumps need a steady flow of water, and solar pumps need sunshine. The biggest difference between these different energies is that fuel can be controlled by the operator, however no one can make the sun shine or make the wind blow at any given moment. Even though the random availability of solar and wind energy seem to be disadvantageous, for the most part wind patterns and solar radiation stay relatively constant form year to year for a given time period. The real problem surfaces when the energy provided by nature at a given time does not overlap the energy needed by the farmer at that same time. All of these issues are further discussed in examining the different sources of energy.

5. Design Matrix A

Design Matrix Power Source		Animal Power	Electrical Power	Wind Power	Human Power	Hydro Power	Solar Power
Design Parameter	Parameter Weight						
Function/Performance	1	6	8	5	4	5	7
Production Cost	1	4	2	6	5	7	2
Available Materials	1	3	1	5	4	8	2
Safety	0.9	8	5	7	8	8	6
Quality	0.8	7	2	5	7	5	9
Reliability	0.8	5	3	5	4	6	7
Mechanical Loading	0.7	4	5	3	4	5	7
Maintenance	0.6	5	3	4	5	6	2
Service Life	0.4	7	5	8	8	8	4
Human Factors	0.4	5	6	8	2	9	8
Total Weighted Average		40.4	29.2	41.2	38.8	49.9	40.1
Ranking		3	6	2	5	1	4

i. Animal Power

When evaluating animal power against human power, advantages of the former are twice as good as the latter. Most agricultural animals are at least 5 to 10 times stronger and more powerful than humans, therefore their water pumping capabilities for irrigation are more productive and efficient. With that being said, by using animals to power water lifting devices, a human can instead focus on distributing water more effectively. Consequently, using animal power for water pumping purposes can replace several humans while cutting on expenses. According to the Indian based Tata Energy Research Institute, about 200 million agriculture animals exist in developing countries around the world. When summed up, these animals have a combined power capacity of about 75 Giga Watts and a principal value of 20 billion US dollars. While a majority of these animals are used in Asia, 80 million of these animals are used in India alone. In order to replace the power produced by these animals, an extremely large automation program would have to be implemented.

One of the main disadvantages associated with animal power is that the animals need to be fed every day of the year, however irrigation seasons usually last anywhere from 100 to 200 days a year. Unlike a mechanical system whose fuel supply can be shutdown while not in use, animals need fuel in order to stay alive and keep in good working condition. In areas where water is close to the surface, animal powered irrigation makes sense. Conversely these areas also tend to hold a high human population which results in a shortage of land. Since animals consume a considerable amount of food, much of the land would be used to simply support the livestock. This is why it would be disadvantageous to use animal power for irrigation purposes alone.

Table 2. Physical Performance Characteristics of Various Agriculture Animals

Animal	Weight (kg)	Pull Force (kg)	Average Speed (m/s)	Power (W)
Heavy Horse	700-1200	50-100	0.8 -1.2	500-1000
Light Horse	400-700	45-80	0.8 -1.4	400-800
Mule	350-500	40-60	0.8 -1.0	300-600
Donkey	150-300	20-40	0.6 -0.8	75-200
Cow	400-600	50-60	0.6 -0.8	200-400
Bull	500-900	60-80	0.5 -0.7	300-500
Camel	500-1000	80-100	0.8 -1.2	400-700
Buffalo	400-900	60-100	0.5 -1.0	600-1000

Several experiments were carried out by O.P Hood to examine pairing horses with water lifting devices. Hood's work showed that two horses paired up with an efficient water lifting system are capable of lifting 270 liters of water per day through a 15 foot elevation. It must be kept in mind that animals need to rest just like humans, therefore it is common practice to work the animal at 3 hour shifts for up to 12 hours a day. In another experiment, Hood used Bulls paired up with a device known as the Stoney Water Lift with a combined animal to water mechanical efficiency of 80%. In a series of tests, a single Bull lifted about 10 liters per hour to an elevation of 7 meters with this setup. Even though a high efficiency was achieved by this system, it was later found that the Bull was performing useful work for only 60% of the time. Hood emphasized that all agriculture animals work most efficiently when exposed to a steady load equal to their pulling force. As a result, in order to increase the overall efficiency, devices are needed which do not produce cyclic loading while pumping water. Many devices, which require the animal to go in circles, can be implemented to prevent cyclic loading. However, when an animal is going in circles, only 80% of its power is being used for creating mechanical shaft work which affects the efficiency of the system.

ii. Electrical Power

At the moment, there is nothing else as cost efficient and convenient as a water pump powered by electricity, if a reliable connection to an electrical grid is available. And that is a big “if” because most rural regions of the world do not have access to any electricity, and the areas that do have access, do not have a reliable electrical infrastructure. Unfortunately, Huamachuco is one of those rural areas where electricity is not readily available to its residents through a conventional electrical grid. The reliability of electricity supply becomes a big problem during the irrigation season. At this time, many farmers tend to use electricity for the purpose of irrigation simultaneously, which causes the local electrical network to overload and cause blackouts. Because of this fact, it is hard to encourage the use of efficient electrical water pumps for irrigation in most developing countries. One option for supplying reliable electricity in rural areas is by extending the power grid, however the cost for this operation is very high and can range from \$5000 to \$15000 per kilometer, depending on the terrain.

If the right infrastructure exists, electric motors are the ideal mechanical power source for pumping water. The amount of water being pumped can be controlled by simply flicking the power switch. Electric motor technology has reached a point where minimum to no servicing is required. The squirrel cage induction motor is the cheapest type of electric motor available in the market today. It is used across the world for many electric power applications. As seen in figure 1 no electrical connections are required for the rotating apparatus in the middle, which means there are no brushes which can wear out over a long period of time. These kinds of motors operate at a fixed speed, which

depends on the power supply frequency and the number of poles in their stator windings. The cheapest type of induction motors run at approximately 1500 rotations per minute. In many regions, it is common practice to use an electric motor inside of a centrifugal pump for irrigation. The biggest problem with induction motors is the fact that over 3 times more current is needed in order to start the rotation, when compared with the amount of current needed when the motors are running at a steady speed. In other words, the peak current that can be supplied by a power grid must be considerably higher than that needed for normal operation. Today, electronic starters exist which help jump start the motor by amplifying the input current. Generally speaking, a higher power rating for an induction motor equals a higher efficiency. At 300W, induction motors are 75% efficient and at 10kW they are 85% efficient. Usually, induction motors are not manufactured in sizes smaller than 100W to 200W due to the high loss of efficiency.

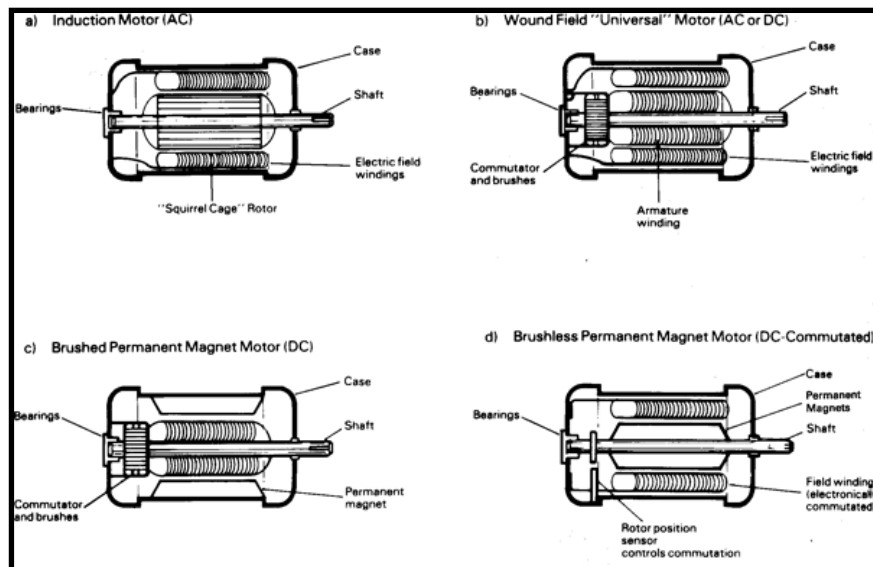


Figure 1. Four Standard Types of Electric Motors

For small scale applications which use a Direct Current power source such as batteries charged from wind turbines or photovoltaic solar panels, the most efficient

option is a permanent magnet motor. Unlike induction motors, the field coils are replaced by permanent magnets, which provide a higher efficiency at lower power ratings in the range of 100W to 200W. Permanent magnet motors require brushed armatures in order to operate, which is a major drawback for pumping because of sealing issues. Because of technological advances, brushless permanent magnet motors have also become available. Mechanically speaking, these kinds of motors are as good as induction motors because they can be sealed for life inside of a submersible pump. However, because of a sophisticated commutator, these motors are relatively expensive when compared with brushed motors. For submersible water pump applications, the motors are commonly filled with clean water which helps equalize the pressure on both sides of the seals and helps cool down the motors. This is obviously only possible with brushless motors because otherwise short circuits would occur.

When it comes to dealing with electricity, safety issues must be addressed in an appropriate manner. Alternating current voltage of about 110V and direct current voltage of 80V are potentially lethal for humans, especially when water is involved. This is why extra caution must be used when combining electricity and water. When using electricity for irrigation purposes, equipment such as fuses and trips must be used and all major components such as the pump and the motor should be grounded. The safest way to install any electrical components is by hiring a trained electrician, but if a person decides to carry out the installation himself, then the work should be inspected by a qualified person. Either way it is always a good idea to know what to do in a case of emergency involving electric shock.

iii. Wind Power

Another energy source that will be evaluated due to its strong potential regarding the project statement is wind power. Wind has been used for many centuries to pump water, and in today's energy conserving environment, wind is being used to produce electricity as well. The most common wind pump that most people recognize is the American farm wind turbine. The main concept of this design is a steel multi-bladed fan-like rotor, which drives a reciprocating pump linkage usually through a reduction gear design, and connects directly to a piston pump located in a borehole directly below the assembly. The main reason these pumps were designed was for the vast demand of the American farmer to water his cattle and help irrigate the crops. The figures below portray the American farm wind turbine and the typical reduction gearbox associated with the design.

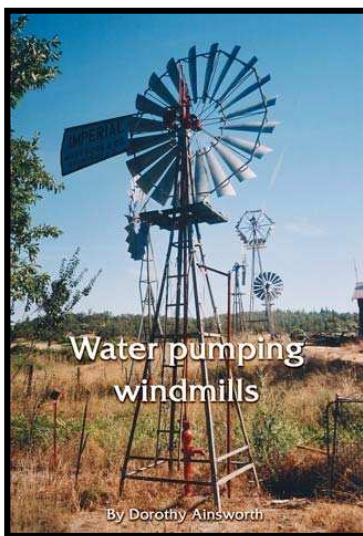


Figure 2. American farm wind turbine

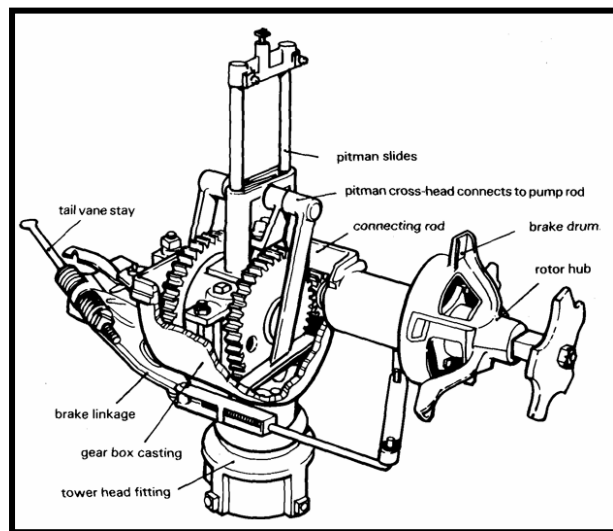


Figure 3. Reduction gearbox directly behind rotor

Wind power can be captured with a wind turbine and used as a wind pump in two distinct ways; one is with irrigation, and the other is for a water supply. The end uses for these

two types, irrigation and water supply, are different through technical uses, and the operational and economic requirements. A water supply pump can be used for irrigation, but usually an irrigation design is not suitable for water supply.

Water supply pumps need to be extremely reliable, and operate unattended for most their lifetime; resulting in being low maintenance designs. A typical farm wind pump should last over 20 years having maintenance once a year, without any major replacements. This is a very demanding technical requirement, making the system somewhat expensive to implement. When further analyzing this design, the group must keep track of the cost effectiveness and also what could be done to make this as cheap as possible without sacrificing the efficiency of the design. The other wind pump design relates to irrigation. These pumps are more seasonal and they involve pumping a large volume of water through a low head. As a result, any wind pump developed for irrigation must be low cost, and since it is for irrigation, the farmer or workers will be present; therefore it is not as critical to design the system to operate unattended.

Now that the most common designs have been examined to capture wind power, some analytical theory should be studied. Understanding the principles of wind and how it can be converted into power is important when deciding which design to move forward with and how efficient the design can be. To calculate the power output of a wind turbine two additional equations are needed. The Tip Speed Ratio (TSR) is necessary to obtain the turbine efficiency, and the efficiency is essential for calculating the power output. The equations below represent the most general formulas for finding the TSR, turbine efficiency, and power in the wind:

$$\text{TSR} = \frac{\omega R_{\text{rotor}}}{V} \quad (1)$$

$$\eta = -0.020554(\text{TSR})^2 + 0.18327(\text{TSR}) + 0.023286 \quad (2)$$

$$P = \eta \frac{1}{2} \rho A V^3 \quad (3)$$

For the overall power output, P is the power available in watts, ρ is the density of air, A is the cross-section of the rotor or air flow of interest, η is the turbine efficiency, and V is the instantaneous free-stream wind velocity. From this cubic relationship, it can be concluded that the power available is extremely sensitive to wind speed. As shown in the table below, doubling the wind speed increases the power available by a factor of eight. With this relationship, finding an area with the highest wind speed is critical for optimal results.

Table 3. Wind speed relative to power output

Wind Speed	mph	6	11	17	22	34	45	67	90
Power Density	kW/m ²	0.01	0.08	0.27	0.64	2.2	5.1	17	41
	hp/ft ²	0.001	0.009	0.035	0.076	0.23	0.65	2.1	5.2

The typical wind pump requires a minimum wind speed of about 2.5 m/s or 5.5 mph to be economically competitive. If the area is sufficient with wind, wind pumps can be one of the most cost effective options. For optimal results, areas that are free of trees, such as savannah grasslands and semi-deserts, are windy and suitable for wind turbine pumps. This should all be considered when deciding where to implement the design. As discussed in the previous report, the area we are concerned with has an annual average wind speed of approximately 10 mph. From the table above, a wind speed of about 11 mph will produce a power density of 0.08 kW/m². This data will be useful when deciding which pump design is most cost effective and energy efficient for implementation.

iv. Human Power

When looking at the problem statement many different energy sources come to mind for pumping water. Further analyzing these sources will give the team a better understanding as to which source will be the most cost effective and efficient to utilize. One source that will be further analyzed is Human Power. Human power is a difficult source to analyze due to the fact each human's capabilities is significantly inconsistent. Also, the many different designs of pumps that operate with human power have a wide varying range of efficiencies in themselves.

When utilizing human power, energy will be burned to result in a power output. Human power is derived from calorific content in their foods. When a person is being physically inactive, energy is still required to run the basic metabolic functions (heart to circulate blood, lungs, digestive system, etc.). Energy for muscle power is then an extra requirement on top of all these everyday bodily functions. Most energy requirements for food in a day, is 2400 kcal, which correlates to 10 MJ or 2.8 kWh/day. The table below indicates the calorific values of many different types of food and the energy obtained from these foods.

Table 4. Calorific Content in Foods

Staple Crop	Energy Content MJ/kg	kg/day to provide 10 MJ
Dayak Rice	10.4 - 11.4	0.92
Iban Rice	13.3	0.75
Tanzania Rice	8.2	1.22
Maize (Africa)	4.2	2.38
Millet (Africa)	3.8	2.63
Sweet Potato (Africa)	10.1	0.99
Cassava (Africa)	15	0.67
Yams (Africa)	9.5	1.05
Groundnuts (Africa)	7.2	1.39

For the average human being, 200-300 Wh/day is their muscular work capability. This basically represents that humans have an average overall efficiency of 7-11% for converting food energy into mechanical “shaft energy”. This is important to understand, because in most any pump design some type of shaft work will be needed. This overall efficiency is calculated with the basic metabolic energy requirements, and the efficiency of muscles for short but strenuous efforts is approximately 20 to 30%. This is particularly interesting since that power can be comparable to an internal combustion engine.

When analyzing different energy sources to use, many believe human power is the cheapest and most cost effective solution right off the back. On the contrary, muscle energy is not all that cheap. Much of the poor are forced to use human power, since other power sources are unaffordable or unavailable. The overall capitol they obtain is not sufficient enough to exhaust other options, leaving human power as their last resort. The next aspect that will be analyzed will show that almost any other source of power could pump water more cheaply, unless only very small quantities are required.

As previously established, the average human work capability is about 250 Wh/day. This correlates to four days of hard labor to produce only one kWh, which could be produced from a small engine burning less than one liter of petroleum fuel. If a farmer uses a small engine operated pumping device, it can be comparable to 20 to 40 men who will work for a wage equivalent to one liter of petroleum fuel per hour. After further observations, if affordable, the farmer will most likely choose an engine operated pump rather than employing 20 to 40 men. This example demonstrates how expensive human muscle power can actually be. If the daily wage of a pumping employee was

equivalent to US \$1.00/day and the energy cost was about \$4.00/kWh, the energy cost would be significantly higher using human muscle power. In this situation, the most cost effective solution would be utilizing an alternative energy source such as solar photovoltaic panels, possibly wind, or even petroleum fossil fuels.

Muscle power can produce heavy loads, but for only a short period of time. The power capability diminishes as the time duration is extended. Another important aspect concerning the power available is the build, age, state of health and weight of the individual; and lastly, the pump design that is being utilized and what muscles the mechanism is exploiting. In the table below, power outputs are displayed concerning how much wattage an individual can produce relative to their age group. These wattages are calculated over a five minute to three hour time span.

Table 5. Human Power Output (in watts) Relative to Age/Time Duration

Age	Human power by duration of effort (watts)					
Years	5 min	10 min	15 min	30 min	60 min	180 min
20	220	210	200	180	160	90
35	210	200	180	160	135	75
60	180	160	150	130	110	60

As seen in the table above, the power output drops considerably as the time duration is extended. Between five minutes and three hours, the power output drops by a factor of 2.5 to 3. For this project statement, the pump is for irrigation meaning time duration will be a critical factor.

Using human muscle as a main power source can result in many different efficiencies. To ensure that you are getting the best efficiency out of the design, the correct muscles must be exhausted. The most powerful muscles are the leg and back muscles, leaving the arm muscles relatively weak. When developing a pump, this information should be closely examined and to extract the most work from an individual,

a bicycle design would be much more effective than a traditional hand pump that utilizes arm muscles. The ergonomics of the design should also be examined; meaning it is important that the operator is comfortable and not contorted into a position that constricts their motion. When using leg muscles, the operator can throw their weight into the process producing better pedal pressure. Studies have shown that converting a rotary hand pump into a foot operated pump improves the output by a factor of three (300%)! Designing a pump that focuses on relaxed posture, is user friendly, and can operate at a comfortable speed should be the main concern.

The most effective irrigation pumps are foot operated. Irrigation pumps are required to operate for several hours at a time, making efficiency and ease of use very critical. Hand operated devices are easier to install, light weight and smaller, but pumping large amounts of water at one time is difficult. Foot pumps are more common for irrigation purposes while hand pumps are more commonly used for filling small containers for a short period of time.

v. **Hydro Power**

One thing that is for sure is that the river will be flowing at the base of the Andes Mountains in Huamachuco. From the information provided by Mr. Mario Diaz we now understand some basic aspects about the source we are drawing from. The average flow rate of the river is approximately 100gal/min during the dry season, which is the season when the pump would be working. Taking this into account, hydro power can be an efficient and reliable source of generating power for a water pump. Hydro power presents some benefits that other alternative energy sources don't. It is and can be available 24 hrs a day, 7 days a week. Also the energy that can be produced by a hydro power mechanism can be easily predicted from river flow data taken over the years.

Most hydro power systems can generate a high power to size ratio. This means that a relatively small head source in area can produce a large amount of power, for running a pump. Since hydro power is generated from flowing or falling water a simple equation can be used to find the power output.

$$P = g \times Q \times H \quad (4)$$

$$P = \text{Power}(\text{watts})$$

$$g = \text{Gravity}(9.81 \frac{m}{s})$$

$$Q = \text{flowrate}(m^3/s)$$

$$H = \text{headsize}(m)$$

By taking these variables into account we can find our maximum and minimum power out puts for our hydro powered source.

Since hydro power typically produces a high amounts of power compared to its size, it may also be concluded that it has a very good power to cost ratio. This is beneficial since the target audience we are attempting to help does not have high income. Hydro power designs are typically very simple causing little or no maintenance. If maintenance is required the mechanisms generating the power can be fixed with minimal effort. Hydro power pumps usually have good efficiency ratings, with ranges between 0.3 and 0.8. Below is a table listing several hydro powered pump designs with their efficiency ratings.

Table 6. Hydro Power Pump Efficiencies

Hydro Power Pump Type	Efficiency Rating (avg)
Undershot water wheel	0.30-0.40
Overshot water wheel	0.50-0.70
Vertical shaft water mill	0.20-0.35
Impulse turbine	0.70-0.85
Reaction turbine	0.60-0.80
Water pressure engine	0.60-0.80
Turbine-pump	0.35-0.50
Hydraulic ram	0.30-0.60

With these high efficiencies come positive results making hydro power very appealing. With the source of energy being available around the clock, the fact that it can be run during the dry season as well as the rainy also that it has a good power to size and power to cost ratio, make hydro power a attractive option of generating power.

vi. Solar Power

One alternative source of energy that is highly underused is solar power. The sun is available anywhere and comes at zero initial cost. In the Huamachuco, the pump will be run during the dry season, were the sun is shining almost every day. Because of this solar power becomes an eye-catching option in the search for an energy source. There are many solar pumps currently on the market, they have built and operated, some have even been engineered to have a large production output of 32,500 GPD. So this proves that it does work and is feasible. In the country of India, a solar power water pump project has been undertaking, and they are producing affordable options for the people. So the initial stigma with solar power being expensive can be thrown away since it is being used in these types of applications already.

In converting solar energy into power for running a pump, two main methods are being used. The first method that can be applied utilizes solar photovoltaic systems, which directly converts solar radiation into electricity. This is done by the use of photocells. Photocells would most likely be the most expensive and fragile piece of equipment in the design of a solar powered pump. The price range of photocells range from The second is to use the heat from the sun, to power a steam engine. This type of solar energy is converted by creating a sort of green house effect, to create the resource to power the engine. Although a viable option photovoltaic systems would be the best option in dealing with the Huamachuco project. Below is a table with the performance characteristics of silicon photovoltaic cells. It can be determined from this figure that when the sun is at its peak the efficiency of energy conversion is about 10%, this would yield about 1000W/m². Figure 4 below describes the efficiency of the cells as the

temperature range increases. And figure 4 also shows the voltage-current characteristic of a solar cell that would yield $1000\text{W}/\text{m}^2$.

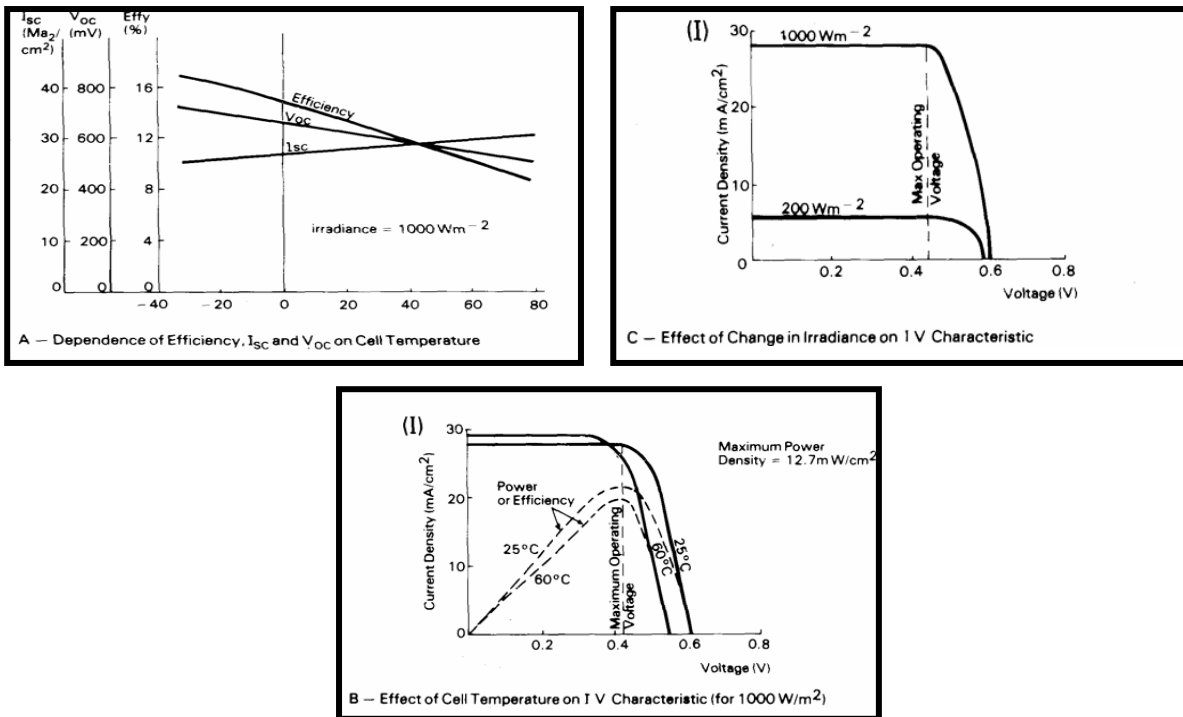
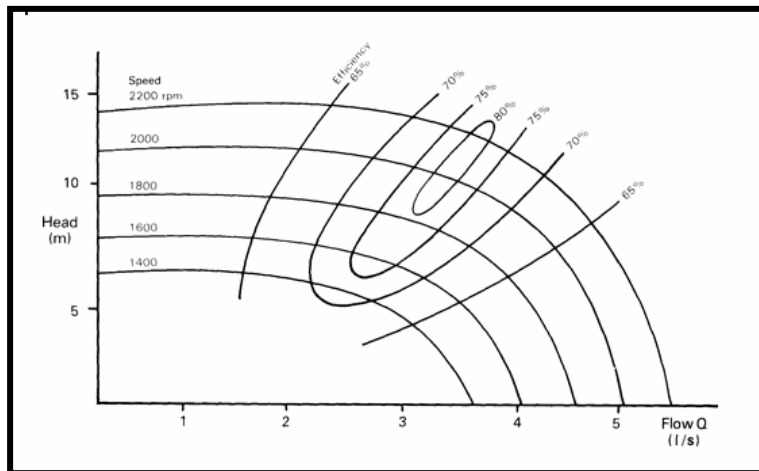


Figure 4. Performance Characteristics of Silicon Photovoltaic Cells

The average solar irradiance at sea level upon the earth is approximately $1000\text{W}/\text{m}^2$. The Peruvian Andes are well above sea level. With this knowledge one can assume that the average irradiance in this region would be much higher. This makes solar power a smart option for this project. With unreliable wind conditions within the Huamachuco region, only makes solar power the more attractive. Overall first costs may be high, since solar panels, photovoltaic cells are not cheap in the long run the initial cost won't be as much. If solar power were to be chosen as the prime energy source, it will be important to note that a structure must be built to protect the solar panels, since they are breakable and replacement would be expensive and a hassle. With the information provided from data and Mr. Diaz, solar power can be and is a viable option.

6. Pump Type

Pumps are used in many everyday applications, from dishwaters, to wells, to the automobiles we drive. Pumps simply displace a fluid from one point to another. Most all pumps can be characterized for practical purposes by measuring their output at different heads and speeds. In the graph below, the performances of different pump types are displayed graphing the head relative to the flow. The relationship between the head (m) and flow (m/s) is dependent on the different speeds of operation. To get the optimal efficiency or production of a pump, the correct head, flow, and speed of operation combination must be correct. It is important to maximize the power output with the least amount of power input. There are many different pump designs, and some are more sensitive to variation. Certain pump types can function with a wide range of operating conditions losing little efficiency, while other designs are very dependent on the speed, flow, and head. The group's assignment is to determine which pump design fits best for the given situation (economic and environmental) concerning the project statement.



Graph 5. Relationship between head, flow, speed, and efficiency of pumps

7. Design Matrix B

Design Matrix Pump Type		Hi-Ram Water Pump	Diaphragm Water Pump	Piston Water Pump	Centrifugal Pump	Air Lift Pump
Design Parameter	Parameter Weight					
Function/Performance	1	7	5	8	9	6
Production Cost	1	9	7	6	4	5
Available Materials	1	8	8	6	3	9
Safety	0.9	9	7	8	6	8
Quality	0.8	7	8	7	8	6
Reliability	0.8	9	6	5	8	8
Mechanical Loading	0.7	5	4	6	7	8
Maintenance	0.6	9	6	6	7	6
Service Life	0.4	6	4	5	8	8
Human Factors	0.4	8	6	6	4	5
Total Weighted Average		59.4	47.9	49	48.1	52.8
Ranking		1	5	3	4	2

i. Hydraulic Ram Water Pump

Developed first by Montgolfier brothers, the hydraulic ram pump is an automatic pumping system which uses the energy from a small fall of water to lift a fraction of the supply water to a much higher elevation. Or to put it in other words, it uses a large volume of water through a small head to lift a small volume of water to a higher head. One of the biggest advantages of the Hydraulic Ram pump is the fact that it barely has any moving parts. The only moving parts are valves, which makes this kind of pump mechanically pump. This simplicity results in high reliability, minimum maintenance, and a long pump life. Another advantage of this kind of pump is that it usually runs 24/7 with a constant flow of water. As long as the water is coming into the pump, the water being pumped out will remain constant. The Hydraulic Ram pump takes advantage of a phenomenon called "water hammer". When looking at most other pumps, they are designed to prevent this phenomenon from occurring, however with the Hydraulic Ram pump this occurrence is welcomed. The figure below does a good job of showing this style of pump in action. There are a total of 10 steps which take place in this process.

1. The waste valve opens under gravity, allowing the water to flow down the drive pipe from the water reservoir through a strainer
2. The flow of the water accelerates down the drive pipe, causing the pressure under the waste valve and the static pressure of the body to increase
3. The resulting forces overcome the waste valve's weight and the valve starts to close
4. When the waste valve starts to close, the water pressure inside the pumps body increases rapidly and slams the waste valve shut

5. The water cannot exit through the waste valve, instead the velocity of the incoming water decreases but the pressure increases causing the delivery valve to open
6. The water then enters the air chamber and the air pressure start to increase
7. Once the air pressure in the air chamber overcomes the static delivery head pressure, it acts like a spring and water is pumped out via the delivery pipe
8. After the air pressure in the air chamber falls close to the static delivery head pressure, the column of water in the air chamber comes to a halt
9. Once the air chamber pressure exceeds the pressure in the casing, the delivery valve closes
10. The reduced pressure in the casing of the pump allows the waste valve to drop open again under gravity and the whole cycle starts over

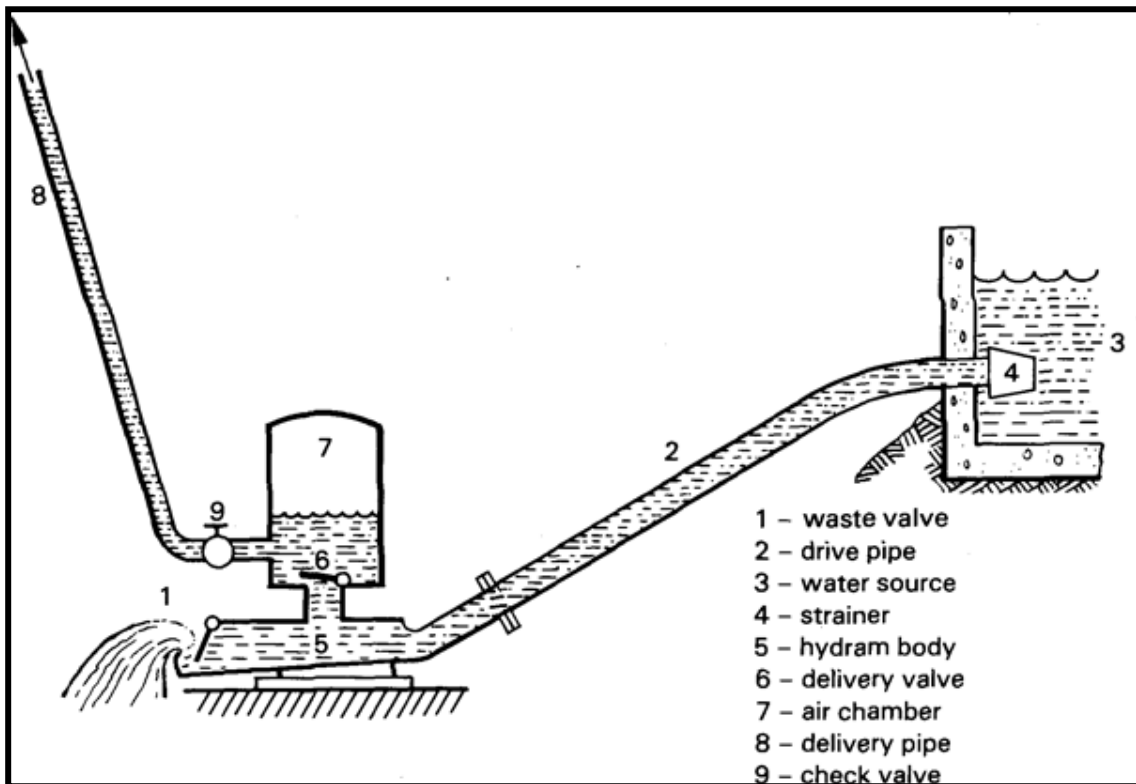


Figure 6. Schematic diagram of Hydraulic Ram Installation

To install a Hydraulic Ram water pump, a supply head needs to be created. This can be done by digging a small hole next to a river to act as a reservoir, or with small streams a barrier can be created and the pump can be installed directly below it. Hydraulic Ram pumps are commonly used for relatively small flow rate applications, however for high flow rate applications, multiple Hydraulic Ram pumps can be installed in parallel to each other. This kind of pump will not work if the drive pipe is not in proportion to the working head. Normally the length of the drive pipe depends on the supply head. The drive pipe should be 3 to 7 times the supply head in length. This means for every 1 foot of supply head, a drive pipe of 3 to 7 feet in length should be used. In order to maximize efficiency, the drive pipe must be as straight as possible to allow the water to flow smoothly. Because of the relatively high shock loads seen by the Hydraulic Ram pump, it is important to bolt down the body of the pump to a concrete foundation to prevent it from shaking loose. Also, the waste valve must never be submerged underneath the water level as this will drown the valve and the pump will cease to function. Unless high head applications are being considered, it is ok to use plastic as the material for the drive pipes. When high head is required, it is better to use good quality steel pipes because of their ability to withstand high loads.

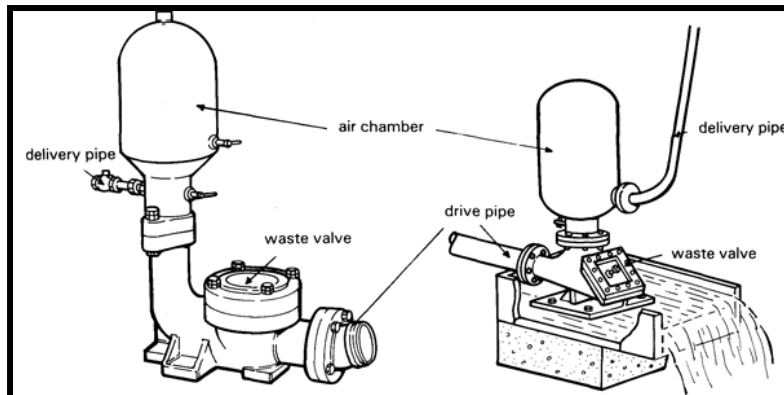


Figure 7. Example of Hydraulic Ram Pumps

Table 7. Hydraulic Ram Input Capacity

Nominal Diameter of Drive Pipe (mm)	32	40	50	65	80	100	125	150	175	200
Driving Water Required to Operate the Pump (liters/minute)	7-16	12-25	27-55	45-96	68-137	136-270	180-410	364-750	545-1136	770-1545

Table 8. Hydraulic Ram Performance

(m) Delivery Head	Supply Head																	
	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	10	12	14	16	18	20
5	144																	
7.5	77	135	220	280														
10	65	96	156	200	260													
15	33	70	105	125	180	215	255	310										
20	59	54	79	100	130	150	173	236	282									
30	20	36	53	66	87	100	115	155	185	216								
40	12	19	33	40	65	75	86	118	140	163	187	212	245	295				
50		15	25	32	51	60	69	94	112	130	149	168	187	225	265			
60			20	24	40	46	53	72	94	109	125	140	156	187	218	250	280	
80			12	16	27	32	36	50	64	82	94	105	117	140	167	187	210	237
100				12	18	20	23	36	48	60	69	84	93	113	132	150	169	188
125					12	14	16	23	34	48	55	62	69	83	97	110	124	140

Table 6 shows the different Hydraulic Ram pump drive pipe sizes and the corresponding minimum and maximum flow inputs required for practical operation. Table 7 indicates the amount of water in liters, pumped within a 24 hour period for a given delivery head and a give supply head. These tables are very useful in determining the critical dimensions and performance characteristics of a Hydraulic Ram water pump for a given application.

ii. *Diaphragm Water Pump*

A different method of pumping water utilizes a flexible diaphragm attached to one wall of a pump which moves water. Two valves are utilized in this pump design, one valve allows the water to enter the pump's body and the second valves allows the water to exit. When compared with other pumps, such as the piston pump, the diaphragm has many advantages and disadvantages associated with its design.

Advantages:

1. The pump is almost perfectly sealed, with the exception of the check valves.
2. It has a high mechanical efficiency because flexing a diaphragm requires relatively little force.
3. It is a self priming pump capable of handling a high suction head
4. The water being pumped does not need to be dirt or grit free

Disadvantages:

1. Material used for the diaphragm must be a high quality rubber, which drives up the cost.
2. Because of the short stroke and large diameter diaphragm, high loads are imposed on the point of attachment of the diaphragm to the pump rod.
3. Diaphragm pumps are not ideal for high head pumping, and are best when used in the 5-10 meter head range.

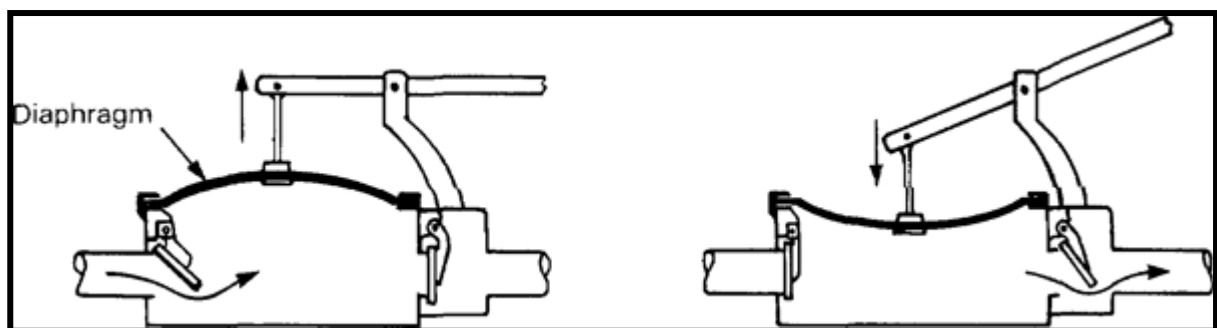


Figure 8. Diaphragm Pump Cross Section View

In figure 9, a foot operated double acting diaphragm pump created by the International Rice Research Institute (IRRI) for irrigation purposes is shown. Only one person is needed for operating this pump. Dissimilar to many other traditional pumps, this device

is portable which allows for much greater flexibility in its application. Therefore, it can be moved from one field to another for pumping water.

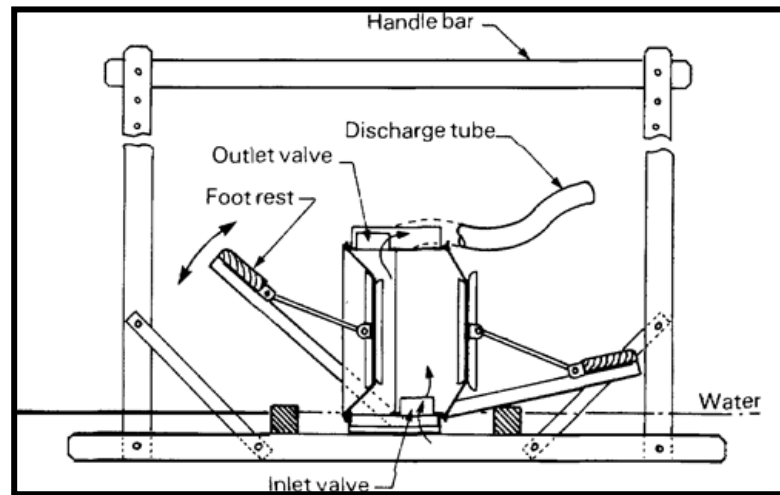


Figure 9. The IRRI Foot Operated Diaphragm Pump

It is possible to make diaphragm pumps out of readily available materials. For example, a diaphragm pump can be created by using an old car tire as the flexible mechanism. In most rural areas around the world, worn car tires are readily available for low to no cost. The basis of this design is to create the main chamber of the pump by end plates into the openings of the tire. This must be done in a way that one end is anchored while the other end can be moved up and down. With the correct check valves in place, this pump can work quite well for high volume flow applications with low head levels. The one downside of using car tires as the flexible member is the amount of force required to pump. A car with an overall diameter of 400mm has an effective area of about 0.125m^2 . This much area requires a force of 125 pounds for every 1 meter of head. With that being said, 3 meters of lift would require 830 pounds of force to lift any water at all. Therefore the connections of the pump need to be very robust to prevent leakage or breaking. Diaphragm pumps made from car tires are capable of pumping water at very high flow rates and work best when submerged in water.

iii. *Piston Water Pump*

After analyzing the power sources that are available for pumping water, many different pump designs need to be looked at. One of the most common and well known pump designs for displacing water is the piston or bucket pump. The following two figures below represent the piston or bucket pump installed on a hand pump, and a blown up view of the piston itself with the internal components. As portrayed in the figures below, water is sucked into the cylinder through a check valve on the up-stroke, and the piston valve is held closed due to the weight of the water above it; simultaneously the water above the piston is propelled out of the pump with the up-stroke. On the down-stroke, the lower check valve is held closed by both its weight and the water pressure, while the similar check valve in the piston is forced open as the trapped water is displaced through the piston ready for the next up-stroke. The figure on the left is demonstrating the down-stroke showing the inlet check valve closed and the piston check valve open.

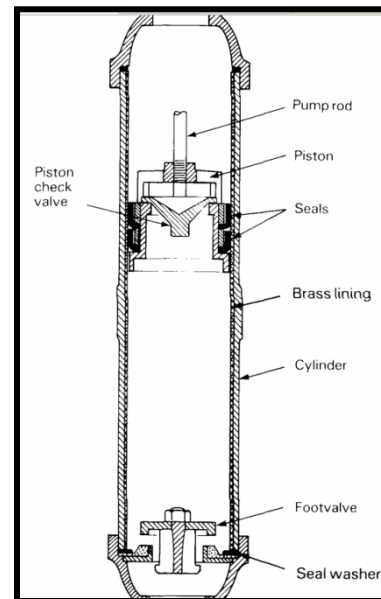
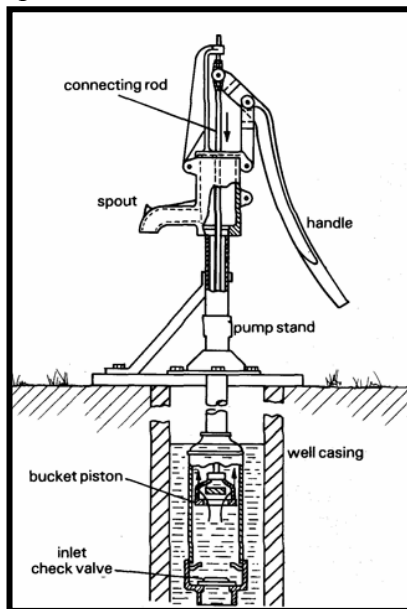


Figure 10. Bucket piston design on hand pump **Figure 11. Enlarged view of piston**

There are many relationships between the output or discharge rate “Q”, piston diameter “d”, stroke length of piston travel “s”, number of strokes per minute “n”, and the volumetric efficiency, which is the percentage of the swept volume that is pumped per stroke “ n_{vol} ”. If “n” is known in strokes per minute (rpm), then the volumetric efficiency should be expressed in decimal form. The relationships between all these variables are shown through the following equations:

$$A = \frac{\pi d^2}{4} \quad (\text{Swept area of piston}) \quad (5)$$

$$V = As \quad (\text{Swept volume per stroke}) \quad (6)$$

$$q = n_{vol} V \quad (\text{Discharge per stroke}) \quad (7)$$

$$Q = nq \quad (\text{Pumping rate per minute}) \quad (8)$$

Another important equation that should be used when designing a piston pump is the force required to lift the piston. This will consist of the weight of the piston, W_p , plus the weight of the column of water obtained in the cross-section of the piston cylinder, H . The dynamic force is also critical which is the summed product of the mass and the acceleration of the moving components (water, plus piston, plus pump rod). The force required to lift the piston is therefore represented through the following equation:

$$F = W_p + A\rho gH \quad (9)$$

where W_p is in Newton’s, A is in m^2 , ρ is the density of water ($1,000 \text{ kg/m}^3$), g is gravity 9.81 m/s^2 and H is in meters; as a result F will be in Newton’s.

The previous piston pump design was a single-acting pump, where water is discharged only on the up-stroke, leaving the down-stroke to fill the chamber for the next

up-stroke. By exploring further designs, it is possible to construct a pump to discharge water on both the up-stroke and down-stroke. These pumps are known as double-acting pumps and are much more productive than single-acting designs. In figure 12, many different pump designs are displayed some focusing on the double-acting designs.

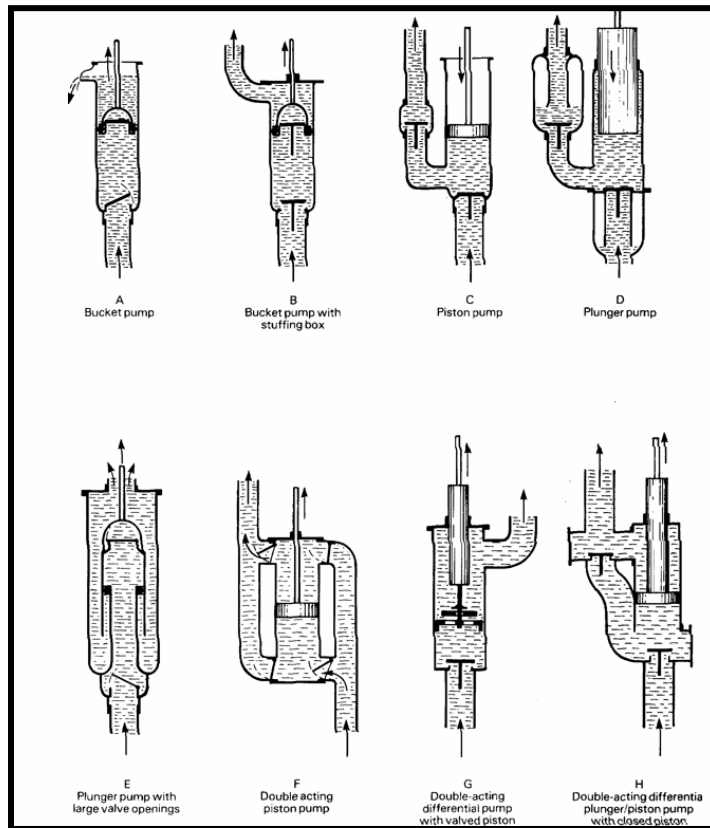


Figure 12. Eight different piston pump designs

Pumps A and B are conventional single-acting pump designs which were examined previously. Pump C is a piston pump that has no check valve in the piston. It is similar to design B, but the disadvantage is the discharge stroke requires the piston to be pushed rather than pulled, which could lead to the rod buckling. Pump D is again similar to C except it is a plunger pump rather than a piston pump. This is a more robust pump meaning the seals are less likely to wear through abrasive solids in the water and

where high pressures and low flow rates are needed, a smaller plunger or closed piston is possible; this is because a through valve is not needed through the center. Pump E has a large valve opening and is used for low head since the high flow rates are required to minimize the hydraulic losses caused by forcing a lot of water through a small opening. Another way to look at pump E is a cylinder is being pulled up and down over a fixed piston. Pump F is similar to C except it is a double-acting design. When the piston is on the up-stroke, it induces water into the lower chamber and discharges through the upper chamber and when continuing through the down-stroke water is induced into the upper chamber and discharged through the lower. Pump G is a differential pump and is double-acting. The pump rod is half the size of the cross-sectional area of the chamber and will displace half the volume of the chamber on the down-stroke. On the up-stroke, the volume will be discharged by the upward movement of the piston. Pump H is again similar to G and is double-acting, but the piston used is a closed piston.

From the pump designs discussed above, A, B, E, and G would be suitable for irrigation. Double-acting pumps can be less effective than single-acting due to the fact they are larger and more complex; resulting in higher expenses. They can experience flow reversal which causes water-hammer, resulting in operating at a lower speed. Lastly there is heavy loading on both the up and down-stroke; as a result the pump rods could experience buckling on the down-stroke with the high compressive forces.

iv. Centrifugal

The centrifugal pump utilizes the use of a turbine or an engine to help generate kinetic energy within the liquid. This is done by a rotating device, which is known as the impeller. The liquid enters the pump, flowing into the center of the revolving impeller, where the liquid is moved, creating a low pressure area, so that more water can flow toward the inlet of the pump. The water is moved in the lateral direction by the centrifugal force created by the impeller, into the diffuser. The diffuser is a stationary part within the pump. Here the pressure is created to move the water out of the pump to the desired destination. In the figure below is a image of a typical centrifugal pump.

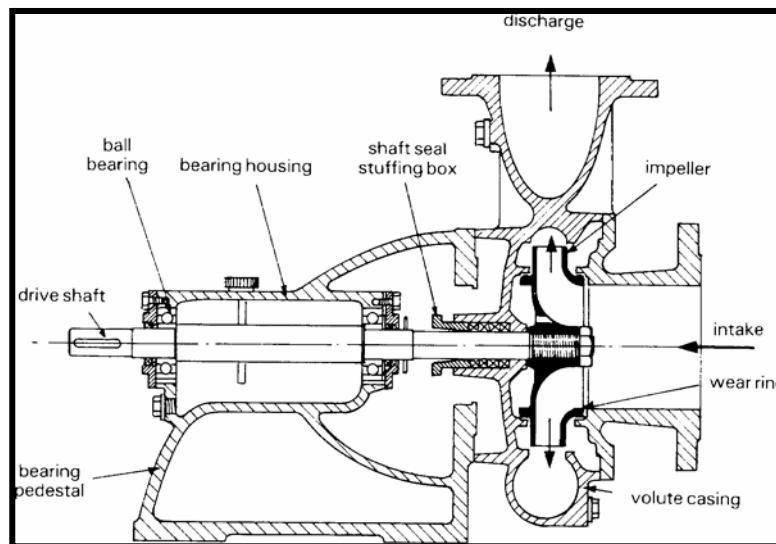


Figure 13. Centrifugal Pump

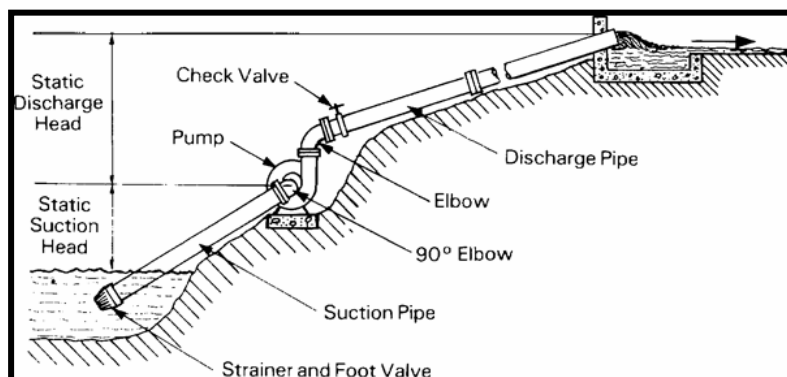


Figure14. Centrifugal Pump Schematic

Since centrifugal pumps employ an engine to help create the power necessary, to create the energy needed a source of energy needs to supply the engine. Centrifugal pump designs utilize alternative and renewable sources of energy. This is desirable when speaking in terms of the Huamachuco project, since normal forms of energy are not readily available and expensive. Solar and wind powered centrifugal pumps have began to appear on the market.

Submersible centrifugal solar powered pumps are a viable and efficient solution to the problem presented. We have been asked to pump water 500ft above the source. One submersible solar powered pump can do this. We know the advantages that solar energy presents, it is available everywhere, and its running cost is free, although initial costs may be high. A submersible solar powered pump can draw water from shallow to deep sources and it can push the water up to 650ft vertically, surpassing our goal of 500ft. It can have a flow rate of approximately 2-85 GPM and 32,500 GPD. So as long as the sun is out the pump is running. Current models on the market boast features that protect against mechanical overload, over-temperature, dry run and over-under voltage. The input voltage range is about 30-300 VDC (Voltage Direct Current) and 90-240 VAC (Volts Alternating Current) or 50/60 Hz. There are models that also protect against salt water and sand. If the source were to contain salt water it is tolerant up to 550 PPM (Particles Per Million). Since our source is being pulled from a river it is key to have protection against sand particles, current submersible solar energy pumps boast 50 PPM tolerance. Below is a figure of what a submersible and non submersible solar power pump would look like.

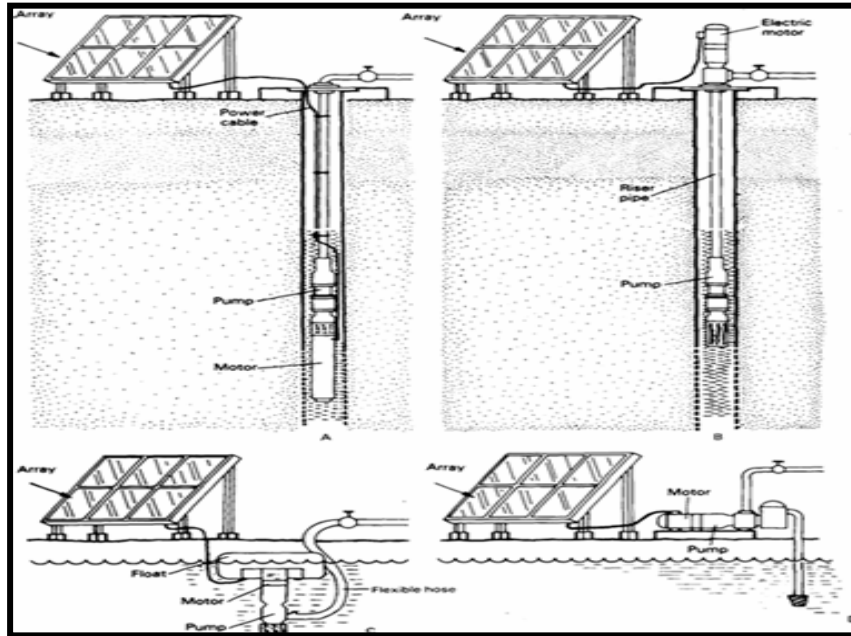


Figure 15. Schematic of Submersible and Non-Submersible Pump

As seen from this data centrifugal pumps are a viable option in creating and developing an efficient pump design for the Huamachuco project. Although they do run the risk of shutting down due to back flow and some can be expensive, this can be prevented. From the specifications of current centrifugal pumps on the market, and there versatility when it comes to an energy source. A centrifugal pump design is definitely an option for the Huamachuco assignment.

v. *Air Lift Pump*

The air lift pump utilizes compressed air which moves down the piped shaft of the pump, this compressed air will aerates the water which in return lowers the density of the water. This in return will cause the density of the water to be almost half of what it is normally, the water will then begin to rise above the water level within the pump climbing vertically. This certain pump can move anywhere between 20 to 2000 gallons of water per minute and can lift the water up to 750ft.

This specific pump utilizes a direct bore, the deeper the bore the better the pump will work. The problem with direct boring, in the region of Huamachuco is that the land there is very hard made up of a lot of clay and rock, causing direct bore to be difficult. Therefore taking a relatively simple and inexpensive design and turning it into an undesirable and costly affair. Although this holds true the air lift pump can and should still be explored as a possible option.

Air lift pumps typically use engine driven air compressors as the basis of influence to compress the air which will help lower the density of the water. The engine that is used can be powered by either, human, electric, solar and wind. All of these options except for electric can be found in the region of Huamachuco. This allows the air lift pump to display its flexibility with natural and alternative sources of energy. The efficiency of the engine driven air compressor plays a large factor within the efficiency of the pump. Although a greater efficiency can be achieved air lift pumps typically are very inefficient ranging from 20% to 30%. Because of the low efficiencies the cost to run the air lift pump will be very high, when basing it off of energy.

One thing that really makes the air lift pump very desirable is the basis of design, build and structure is that it has no moving parts. By not having anything within the system that moves, it cuts down on certain design aspects, and possible breakdown within the system. The pump will be able to be easily installed and work on if it were ever to fail. It turns out that by having no moving parts that the pump is very reliable, and it can handle sandy and gritty water with fair ease. This is nice because it means in the Huamachuco area the pump can be run year round. One drawback to the river is that during the rainy season there are many types of sediment that get carried downstream, but the high tolerance to these effects make the air lift pump pleasing.

In the figure below is a basic schematic for a typical air lift pump. It can be seen how it utilizes the natural effects of compressed air, to cause the aerating of the water. The immersion length is the depth of the pump; the deeper the immersion the higher the water can be typically pushed.

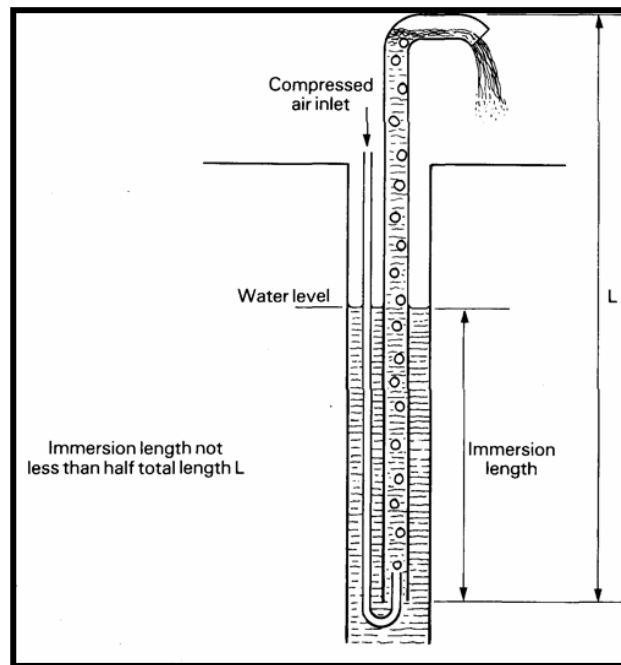


Figure 16. Schematic of Air Lift Pump

8. Materials

One of the most important parts in looking at pump designs is the materials used. Many materials are not sufficient in designing pumps, either because they are not strong enough or they are easily corrodible, both terrible things. When designing a pump, and looking at the whole system, the pump itself, the piping and the structural material there is five main criterions to look at. The corrosion resistance of the material and how it will exist when it is placed under wet conditions. The second is the resistance to wear and abrasion since many components within the pump will be moving and rubbing against each other, also many of the components are in contact with flowing water that may be carrying abrasion materials such as sand. The third is cost, this is especially important in the Huamachuco region and other impoverished areas, as a team we want to supply them with an efficient yet cost effective pump. The fourth is the strength of the material, this is important since the components will constantly be put under stress and pressure, they will also have to be able to have a long life span, and resistant to fatigue. The fifth and final criterion to look at is the availability of the material, is this material available in all regions or is it specific, we have to use materials that will be readily available anywhere, if we plan on supplying a pump that may also be fixed if needed. It is important to take all of these into account when designing and building water pumps. This section will break down all the different material types with strengths and weaknesses.

9. Design Matrix C

Design Matrix Materials		Ferrous Metals	Non-Ferrous Metals	Timber	Plastics
Design Parameter	Parameter Weight				
Function/Performance	1	4	8	3	6
Production Cost	1	3	3	8	7
Available Materials	1	5	4	7	6
Safety	0.9	7	8	8	8
Quality	0.8	4	7	5	8
Reliability	0.8	5	8	7	5
Mechanical Loading	0.7	9	8	7	4
Maintenance	0.6	5	6	4	7
Service Life	0.4	4	8	6	7
Human Factors	0.4	7	7	8	9
Total Weighted Average		39.2	49.4	47.7	50
Ranking		4	2	3	1

i. Ferrous Metals

Ferrous metals are readily available anywhere in the world, making them a desirable option in the production of a pump. Not only are these types of metals widely accessible they are known for being a low cost, strong metal. Most ferrous metals have an iron base; because of this they are susceptible to high corrosion rates. This makes ferrous metals undesirable in the production of the actual pump. One common error made with ferrous metals is in the use of cast iron pump cylinders. The reason this is a misuse of the material is that if it were to sit for a period of time, it would oxidize forming rust, which in return would wear out the piston seals, causing an overall failure within the pump.

Typically stainless steels, which is the Rolls Royce of ferrous metals, can be used effectively in the place of bronze and brasses since they are not as in danger of corrosion. Though this holds true stainless steels are hard to machine and expensive. This is why many pump manufacturers actually prefer non-ferrous metals which are corrosion resistant. Stainless steel nuts and bolts have proven to be effective, than those made of milder grade steels. This is due to the fact that stainless steels are less likely to corrode giving them a longer life span, creating fewer repairs.

Like it was previously stated many milder graded steels are more likely to corrode compared to other metals. Although this type of ferrous metal is vulnerable to corrosion, these metals can be protected from the dreaded oxidation process. A few ways that this is done today is by galvanizing the metal or coating/plating it in zinc. They can also be coated in paint, or have corrosion inhibitors chemically bonded to the surfaces. All of this can be done to limit the chance of corrosion, but may raise costs of the material.

One way, ferrous metals are used very effectively in the design of pumps. Is that since these metals are readily available, cheap and strong, they are good for structural use. They are effective in this type of use because they are not in contact with the water regularly. Although this holds true, Huamachuco does have a rainy season where there is a lot of rain fall, this would expose the ferrous metal structures to high amounts of water, possibly causing rust to occur. Ferrous metals are a viable option in the design of a pump structure, but they should not be used in the design of the pump itself, or the piping of the pipe.

Table 9. Material Properties of Different Ferrous Metals

NAME	ALLOY OF	PROPERTIES
Mild Steel	Carbon 0.1 - 0.3% Iron 99.9 - 99.7%	Tough. High tensile strength. Can be case hardened. Rusts very easily.
Carbon Steel	Carbon 0.6 - 1.4% Iron 99.4 - 98.6%	Tough. Can be hardened and tempered.
Stainless steel	Iron, nickel and chromium.	Tough, resistant to rust and stains.
Cast iron	Carbon 2 - 6% Iron 98 - 94%	Strong but brittle. Compressive strength very high.
Wrought iron	Almost 100% iron	Fibrous, tough, ductile, resistant to rusting.

ii. Non-Ferrous Metals

In reciprocating pump cylinders, a commonly used material is brass. Because of the high costs associated with this metal, thin brass tubes are often used inside the cylinder casing as liners, instead of thick brass cylinders. Because of its corrosive properties, steel must not be kept in direct contact with water for a long period of time, hence the use of brass liners. When it comes to resistance against wear in sliding situations, brass holds up much better than steel, however brass is a relatively weak metal when exposed to tensile loads. Bronze and gun metal are a big family of alloys based on copper. Generally speaking, these metals are quite expensive but possess all the advantages of brass with the addition of being structurally stronger when exposed to tensile stresses. Bronze can include chromium or nickel in a variety of grades, along with copper alloyed with tin, and small traces of materials such as manganese, lead, and iron. Some lead based bronze metals reduce costs by replacing tin with more lead, while maintaining good material qualities for pump applications. Gun metal is formed by combining zinc and lead in multiple proportions with bronze. This material is very useful for high corrosive and stress environments. Another material called aluminum bronze replaces its tin content with aluminum, which greatly reduces costs. When it comes to making precise components for water applications, bronze metals are among the best. It is a very user friendly material for creating precisely machined parts. Analyzing material such as aluminum and other light alloys, it is found that they are not wear resistant or hard enough for many pump applications. However because of their light weight, these materials maybe used for making pump pipes. Aluminum and light alloys are not very cost effective either, which makes them a more unfeasible option.

Table 10. Material Properties of Different Non-Ferrous Metals

Name	Composition	Properties
Aluminum	Pure Metal	Grayish-White, soft, malleable, conductive to heat and electricity, It is corrosion resistant. It can be welded but this is difficult. Needs special processes.
Aluminum alloys	Aluminum, +4% Copper, +1 %Manganese	Ductile, Malleable, Work Hardens.
Copper	Pure metal	Red, tough, ductile, High electrical conductor, corrosion resistant, Can work hard or cold. Needs frequent annealing.
Brass	65% copper, +35%zinc	Very corrosive, yellow in color, tarnishes very easily. Harder than copper. Good electrical conductor.
Lead	Pure metal	The heaviest common metal. Soft, malleable, bright and shiny when new but quickly oxidizes to a dull grey. Resistant to corrosion.
Zinc	Pure metal	A layer of oxide protects it from corrosion, bluish-white, easily worked.
Tin	Pure metal	White and soft, corrosion resistant.

iii. Timber

Choosing which type of material to use when building any design is very pertinent to the process. Once the design is sketched out and the tolerances established, finding the right material to satisfy all the stresses and strains of the mechanism must be met. One material source that is always considered due to its easy manufacturability and cost is timber/wood. There are many types of wood and it ranges in density from 500 kg/m³ up to 1300 kg/m³. Wood also has large variation in its mechanical properties, its workability, wear resistance and properties when in wet conditions. Other settings that need to be considered when working with wood, is how vulnerable it is to damage by insects, fungus or fire.

Greenheart, Iroko, Jarrah, Opepe, Teak and Wallaba are all durable hardwoods that should be considered when designing with timber as a material source. In some cases, wood is treated to improve its durability and preserve the surface exposed to Mother Nature. Some of the most effective treatments include pressure impregnation with tar, or water-based preservatives. Since the mechanical properties of wood are not uniform throughout, careful consideration should be made as to where certain stresses can be applied to the wood. Another type of wood often utilized, is plywood and chipboards. In this case, the adhesives used to bond the wood together are most important. Most plywood is bonded with urea-based adhesives which are inadequate for water resistance or outside use. If bonded with phenolic resins, they are much more suitable for water or outside use. Another way to protect woods and prolong the lifetime wear is by applying paint to the exposed areas. Paints are always a good way to protect any surface from wear and deterioration.

iv. Plastics

Another material selected for this project statement was plastics. There are many different types of plastics, but three main categories will be explored in this report. The first is thermoplastics, which softens when heated and can be heated and worked, molded or extruded. The next is thermosets, which are heated once to form them with an irreversible chemical process. The last type of plastic we will analyze is catalytically-cured resins, which comprise of a composite tube with some kind of inner liner to enhance strength and durability. Although plastics are weaker and softer than metals, they do have qualities such as being corrosion free and lower costs for mass production piping that metals lack.

Thermoplastics are generally the cheapest plastics, and the one most commonly used for irrigation includes polyvinylchloride (PVC). PVC is used for extruded pipes and can be rigid or flexible. It is important to know that certain grades of PVC are suitable for drinking water, while others are not since traces of toxic plasticizer can be present throughout the inner lining. PVC can be relatively cheap and durable, but when exposed to sunlight (UV rays) it can be damaged; meaning the piping should be buried underground or painted with a finish to prevent penetration from UV radiation. Since PVC is a thermoplastic, when heated above 80° C it will soften. If the above precautions are met this will not be a problem, and the application it is used for, is usually in a wet environment.

Instead of using PVC, polyethylene is used which can be cheaper and less brittle; especially at low temperatures. This is commonly seen in black flexible hoses used for irrigation and the structural casing is much weaker than PVC, not necessarily making this

a disadvantage when used with a low pressure system. If the system requires high pressure then PVC would be the better choice. Polypropylene is a plastic polymer very similar to polyethylene. The main difference is polypropylene has a much higher melting point relative to other plastics, 160° C, meaning the plastic is less prone to experiencing any warping. For our design, cold temperatures are more critical than hot melting point temperatures since we are dealing with pumping water for irrigation.

Instead of using thermoplastics, thermoset plastics are used due to their durability, strength, wear resistance and heat resistance. They are commonly found in pump applications as bearings, pump impellers, or pump casings. Most plastics will deform over a long period of time if permanently loaded, this can be avoided by thermoset plastics. Various polyesters and epoxides are used to make glass reinforced plastics which can be found in small tough components, casings, or large tanks. Another example of composite plastics is the phenolic composites where cloth and phenolic resin are combined to make a very tough and wear resistant, but easily machinable, water lubricating bearing.

10. Design Recommendation

After conducting a State of the Art evaluation of 30 possible water pump designs for the purpose of irrigation, the following can be concluded. The best power source option for Huamachuco is Hydro Power. Hydro power possess many attractive advantages when compared with other power sources. Unlike solar, wind, animal, and human power, hydro power is available in Huamachuco 24 hours a day, 7 days a week. Another advantage of hydro power is the fact that it is relatively easy to capture and compared with electricity, hydro power is much safer to work with. Since it is more dense than wind and air, the energy captured from water can be more readily converted into mechanical energy thus reducing cost and increasing the efficiency of the overall system.

The Hydraulic Ram water pump was chosen as the best pump type due to the following reasons. The Hydraulic Ram is essentially a maintenance free system which is mechanically simple with incredible reliability. It is very simple to build and in a sense, employs "free energy" to operate. The pump itself has a total of 2 moving parts, and both of them are valves. This is the least amount of moving parts, when compared with all of the other designs. Fewer moving parts translates in to better efficiency with minimum to no maintenance requirements and increased reliability. The design itself is very flexible and can pump water anywhere from 5 meters to 125 meters vertically. Perhaps the best advantage of the Hydraulic Ram is the fact that it is capable of operating 24 hours a day, 7 days a week without any human supervision. This particular aspect of the pump matches perfectly with hydro power because the river in Huamachuco also flow for the same time period. Installation for this pump is also relatively easily and can be carried

out by anyone because it mainly requires digging. If the correct materials are chosen, the Hydraulic Ram water pump can be built from scratch for under \$100 dollars with locally available materials. However, if these pumps are produced in a greater quantity, then the price is sure to decrease.

After comparing the properties of different materials, the results showed that plastics should be utilized to their fullest in the construction of the pump along with some non-ferrous metals. Plastics are extremely efficient in corrosive water environments, and are relatively cheap when compared with metals. In fact most of the water pipes installed in newer homes are made of PVC. Even though metals are capable of withstanding higher loads, the elevated costs associated with the group does not justify them as a feasible option. Plastic pipes are becoming more available in a variety of sizes in most rural areas around the world. With that being said, it is much easier to connect two pieces of plastic instead of two pieces of metal. With metals, welding is the best way to seal a joint, however plastics can be glued or screwed together. Therefore it is easier to manufacture with plastic materials. The final design recommendation consists of capturing hydro power and using it to drive the Hydraulic Ram water pump made mostly from plastics and some non-ferrous metals.

11. Manufacturing

In this section of the report, the materials needed to fabricate and assemble the Hydraulic Pump will be discussed. According to the problem statement, one of the group's main goals was not only to create a working prototype, but to do so in the most economical way possible. We wanted to set a goal of \$200 or less, that would utilize some type of renewable energy, or very little nonrenewable energy.

Many different designs were analyzed and compared to ensure the most efficient design would be chosen. The group evaluated human powered, wind powered, and water powered pump systems. Each category had multiple pump designs associated with them, but ultimately the hydraulic water pump proved most economical, simplistic, and efficient for the given problem statement. Other pumps that were closely considered included, hand powered pumps, wind powered pumps, water wheel pump, and solar powered pumps. All of these designs had their advantages along with their disadvantages. For the hand powered pumps, human power would be required to move the water, making them very inefficient. Wind powered pumps, or wind-mills, are a traditional way to move water, but the water source must be directly under the wind-mill or very close. This design also has a lot of moving parts, making it more prone for maintenance and relatively expensive to manufacture. Water wheel pumps are not very efficient and would not satisfy the problem statement to its fullest. This design would also be difficult to implement in the given region. Another pump design that was closely examined was the solar powered pump. Again this design would be expensive to implement, and maintenance would be difficult to pursue for the average Peruvian resident.

The design that was ultimately chosen requires little moving parts, is almost maintenance free, and simplistic. As shown in figure (3), the overall complexity of the pump is minimal. Since there are virtually no moving parts, the maintenance is simple, and replacing a part can be done by the average Peruvian individual. The main advantage to this pump, besides the simplicity and minimal maintenance, is the cost of the design and energy utilized. The entire pump is less than \$100 dollars, and the energy used to operate the pump is a water reservoir (body of water or river) or renewable energy.

In figure 17 below, the materials and parts for the pump are numbered and further explained.

- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 1. 4" PVC Cap | 8. 3/4" Ball Valve |
| 2. 4" x 24" PVC Pipe | 9. 4" x 2" Reducing Fitting |
| 3. Brass Swing Check Valve.
There is an arrow on the valve which indicates the direction of flow. This arrow should be pointing toward the pipe when connecting the valve. | 10. Cans of Primer and Cement |
| 4. 1-1/4" Ball Valve | 11. Spring Check Valve |
| 5. 1-1/4" Union | 12. 1-1/4" Tee Fitting |
| 6. 1-1/4" x 3/4" Bushing | 13. 1-1/4" Tee Fitting |
| 7. 3/4" Union (Ours can thread to a garden hose, otherwise it will connect to 3/4" PVC pipe) | 14. 3/4" PVC Pipe (Used to connect 3/4" Ball Valve to 1-1/4" x 3/4" Bushing) |
| | 15. 1-1/4" Pipe Section |
| | 16. 1-1/4" x 2" Bushing (Will connect to the 4" x 2" Reducing Fitting) |
| | 17. 1-1/4" Pipe to Thread Fitting |

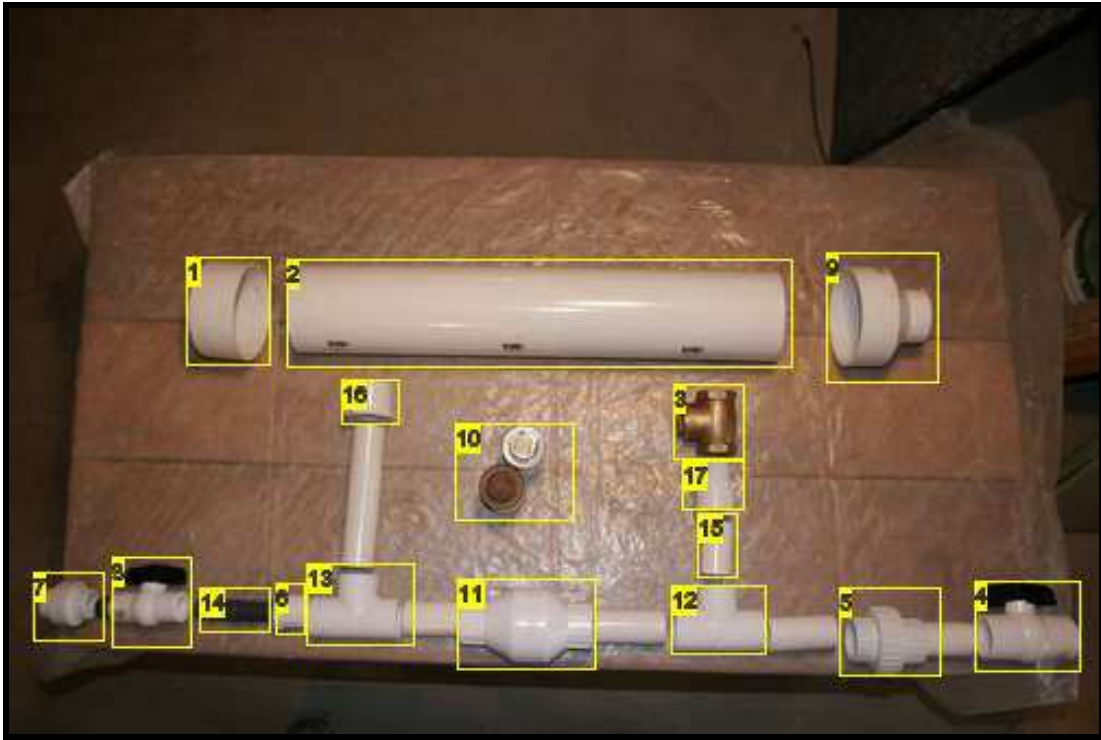


Figure 17. Exploded View of Hydraulic Pump

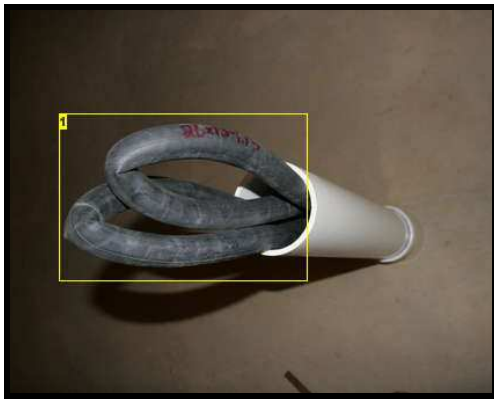


Figure 18. Partially Inflated Bike Tube for Pressure Chamber¹

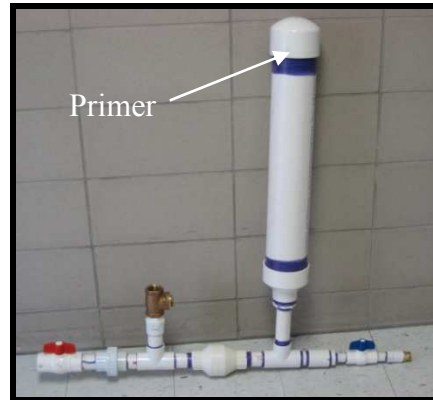


Figure 19. Fully Assembled Product

After purchasing all the materials, the pump can be assembled together.

Figure 17 lays out where each piece should be assembled and the final product is shown in figure 19. The entire parts list can be found at a Lowe's, but some of the components can be improvised with other similar pieces. The PVC pieces can be purchased as smooth or threaded attachments, so make sure to match everything accordingly. If both attachments are smooth, assemble the pump with PVC primer and PVC cement. First a coat of primer should be applied to the entire outer diameter of the PVC pipe (which is purple and can be seen in figure 19) that will be connected. This should take a few minutes to dry and then the cement can be applied to the area that has primer and the two pieces can be assembled together (make sure to twist while assembling pieces together and hold firming for 30 seconds). If the pieces are threaded, first apply Teflon Thread Tape around the threads and twist them together (this will be needed for the brass swing check valve). Before assembling the large pressure chamber, shown in figure (18), a partially inflated bike tube should be placed inside (also referred to as a bladder). This will ensure that the pressure is kept constant in the chamber and the air doesn't absorb entirely in the water. After assembling all the components together, the pump is ready for installation.

12. Installation

In order for the Hydraulic Ram Pump to work properly, it is absolutely essential for the system to be installed correctly. If the pump is not installed correctly, then the performance will be greatly hampered and the pump itself might not work at all. As stated before, the main consideration in installing a Hydraulic Ram Pump is staying true to the optimal slope of the drive pipe. For every 1 foot of rise in the inlet head, the drive pipe must be approximately 3 feet long. For example, if the inlet head is 5 feet high, then the drive pipe used for the pump must be 15 feet long. Similarly, if the inlet head is 10 feet high, then the drive pipe used for the pump must be 30 feet long. Keeping this rise to run relationship during installation will ensure the optimal performance for the Hydraulic Ram Pump.

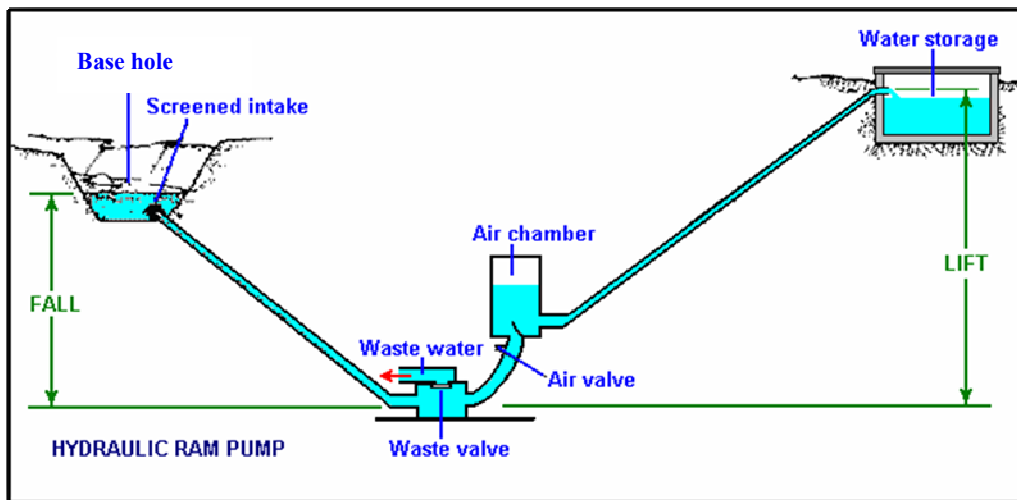


Figure 20. Hydraulic Ram Pump Installation Schematic

The drive pipe itself can be installed at the source of running water, or a reservoir of still water. If the water source is not clean, it is important to install a fine mesh at the inlet of the drive pipe to prevent any dirt from entering the system. One of the biggest issues with Hydraulic Ram Pumps is clogging. Clogging can greatly reduce the

performance of the pump and can even cause the pump to stop working all together. Therefore it is absolutely essential to install a fine mesh at the inlet of the drive pipe to prevent clogging. The drive pipe must be kept as straight as possible because any bends or curves in the pipe will result in a less efficient system. One of the most effective installation methods consists of digging a small hole next to the water source and installing the drive pipe inside the smaller hole.

1. Find clean ground next to the water source with a slight slope
2. Dig a base hole 3 feet away from the water source with a diameter of 3 feet and depth of 2 feet
3. Connect the base hole to the water source with a small canal
4. Connect the drive pipe to the Hydraulic Ram Pump's inlet while ensuring the rise to run relationship of 1/3 is kept
5. Place the Hydraulic Ramp Pump such that the air chamber is straight up and close the inlet valve
6. Install a fine mesh at the inlet of the drive pipe and insert the drive pipe at the base of the base hole
7. Connect a pipe from the outlet of the Hydraulic Ram Pump to a reservoir placed at a higher output height
8. Make sure all connections are tight and leak free
9. Once all connections have been secured, open the inlet valve of the Hydraulic Ram Pump
10. Initially the pump's butterfly valve will stay closed, therefore the pump must be primed by manually pushing the butterfly valve open up to 10 times

13. Testing/Results

After constructing the first prototype, the team tested the Hydraulic Ram Pump design under different conditions. Since a river could not be easily accessed for the purposes of testing, the team decided to simulate the flow of a river by filling up a 5 gallon bucket with water. A conventional backyard water tap was used to act as the water source. The flow rate of the water source was simulated to be 6.92 gallons per minute. A 1.25 inch hole was cut at the base of the 5 gallon bucket to install the drive pipe. Next, the drive pipe was installed at the inlet of the Hydraulic Ram Pump and a 50 feet garden hose was attached at the outlet. A total of two trials were carried out to test the performance of the pump.

Trial 1

- Inlet Pipe Diameter: 1.25 inches
- Outlet Pipe Diameter: 0.75 inches
- Inlet Height: 1.5 feet
- Outlet Height: 10 feet
- Inlet Flow Rate: 6.92 gallons per minute
- Outlet Flow Rate: 0.59 gallons per minute, 849.6 gallons per day

Trial 2

- Inlet Pipe Diameter: 1.25 inches
- Outlet Pipe Diameter: 0.75 inches
- Inlet Height: 4.5 feet
- Outlet Height: 30 feet
- Inlet Flow Rate: 6.92 gallons per minute
- Outlet Flow Rate: 0.66 gallons per minute, 960 gallons per day

After conducting two trial runs, the results obtained from the Hydraulic Ram Pump look very promising. Outlet flow rate of 0.59 to 0.66 gallons per minute maybe be very small, however since this pump is designed to operate 24 hours a day, up to 960 gallons per day can be pumped inside of a reservoir. From the different trial runs, the team was also able to extrapolate and estimate the performance characteristics of the pump over a range of different inlet heights. As can be seen in the figure below, the relationship between the inlet height and the outlet height is linear. For every 1 foot of rise in the inlet height, the pump is able to pump water 6.66 feet high at the outlet. These results imply that the design works just as intended with very close to nominal results.

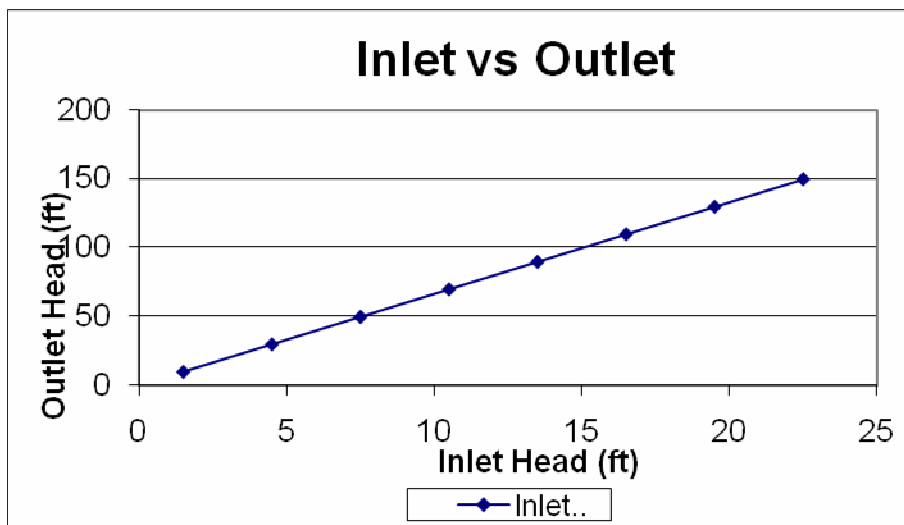


Figure 21. Testing Results

14. Irrigation

The landscape of the Peruvian Andes region provides farmers with a great challenge. The success of these farms depends upon several factors including water supply, altitude and soil fertility. Much of the Andes are limited in usable land due to the structure of the mountain side and the soil make up. Since the Andes are composed of a rocky terrain much of the soil follows suite. The ground is hard and the composite in the soil is not particularly fit for crop growth. The altitude of these farms can exceed 500 meters, causing climate change from day to night and putting efficient water sources out of reach. The altitude causes the water supply for many of these farms is scarce. Farming must be planned around the rainy season. Currently there is approximately 1.7 million hectares of cultivated hectares in Peru that may have some irrigation system available. But out of that 1.7 million only 1.2 million hectares are actually irrigated regularly each year. Below is a table that shows the amount of land and how it is currently used in Huamachuco.

Table 11. Land use by Hectares in Huamachuco

Uses of Land	Land Surface (Hectares)	%
Agricultural Area	60,616	40.35
• Irrigation	10,411	• 17.2
• Rainfed	50,205	• 82.8
Non Agricultural Area	89,611	59.65
• Pasture	62,214	
• Forest	9,351	
Other	18,047	
TOTAL	150227	100

This is due the lack of an efficient water source and poor performance from irrigation systems. Currently about 80 percent of the water withdrawal in Peru is used for irrigation and of that 80% percent 65% of it is wasted due to inefficient systems. The Peruvian Andes region crops are being irrigated by a canal or furrow system. This specific

irrigation system uses the natural effects of gravity to flow the water down the mountain side, in channels or canals. It is an open canal system that is typically unlined with any material to stop saturation of water into the soil. Water flows from the source down the canal and is then distributed down to field rows. The current system is effective in supplying the water but it is relatively inefficient currently at 35% efficiency. Some disadvantages to this system involve the terrain, since it's a rough terrain channels are often difficult to construct, causing long intense labor hours for an inefficient design. Typically these systems although they work lose a decent amount of water to run-off and evaporation this is what causes the low efficiencies. The current canal system also degrades the landscape. It not only destroys the environment but can create danger to individuals in the area. These hazards include mud slides and rock falls. The canal system is also wasteful it unevenly distributes the water to the crops, leaving areas un irrigated and over saturation others. Although all of this is true currently with the cost of other systems the furrow system is the cheapest. It has also been practiced in the region for a long time allowing for individuals to understand how it works. It also has a very low maintenance and relies only on the effects of gravity. With this being said two more systems should be reviewed to see if there is a more efficient way of distributing the water from the pumped source.

A common system used throughout the world to irrigate crops is a sprinkler system. There are many types of sprinkler systems in place, but they all face the same common problems. Typically sprinkler systems are an overhead irrigation method. It takes advantages of sprinklers, sprayers and guns which are installed on a structure overhead of the crops. It faces problems with efficiency since the majority of the water is

evaporated before it is used. This in return can provide poor results and can be deemed wasteful. Also with the landscape within the Peruvian Andes this type of system would be very hard to install. The terrain would provide challenges in developing an efficient design. It may also cost more money since a pressurized pump and possible electric system would need to be installed. It really isn't applicable to this mountain region.

Drip irrigation is composed of a network of pipes, valves, and tubing spread throughout the farming area that minimizes the use of water by forcing the water to drip slowly at the roots of the plants or directly onto the soil surface. Most drip irrigation systems are about 90% efficient, which allows for maximization of the water supply and greater water savings. This type of system achieves such a high efficiency because it reduces the effects of evaporation and deep drainage. In regions like the Peruvian Andes where water supply is limited, drip irrigation systems can increase crop production while using the same amount of water as before. This particular system also minimizes soil erosion and allows for soil types to not play a large role when irrigating. It can be installed on hilly terrain and has the ability to irrigate odd shaped fields. Since the system is typically operated at a low pressure it reduces the cost of energy. To create the energy needed to pump water through the drip system, the hammer pump or natural effects of gravity may be used. A reservoir should be created to allow for storage of the water being pumped from the river or source. This will allow for a new source at the desired elevation, the hammer pump or gravity may then be used to create the water flow through the system. A series of valves to control when the field will be irrigated can be installed, to allow for control over the system. Overall this system can be built with cost effectiveness and it would provide the region with the best form of irrigation.

15. Conclusion

In conclusion, this report has given the group enough information and statistics regarding power sources, pump designs, and materials to use, to choose the best design possible. Our main goal for this report was to further analyze every different pump design combination displayed on the design matrix, so when choosing and rating each design the group would pick the best one possible. Forming a design matrix is a logical and smart approach to take in any project assigned to an engineering team. This is a systematic way of assuring the correct design is chosen without any premature decision making. With our design matrix, 30 different possible pump combinations could be chosen, providing the group with plenty of viable options. After extensive research and analytical thinking, the group has decided to pursue the Hi-Ram pump design. We feel this design will satisfy the project statement requirements the best and will be the most cost effective design to pursue. Since the region of Huamachuco is poverty stricken, one of the main concerns needed to be the overall capital costs of the design and implementation. Hopefully this pump will improve the communities well being and perform its duty of pumping water for irrigation.

16. References

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