WATERBOYS DRLG.

Water Well Drilling in Alluvial Soils

Sponsors:

Bob Hather

Tim Cleath

Prepared By:

Brendan Ochoa
Bmochoa@pacbell.net

Matt Davis
Mdavis02@gmail.com

Joe Engel
Joseph.powell.engel@gmail.com

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INTRODUCTION

WATERBOYS DRLG is a team of Cal Poly students who are focusing their efforts towards a practical solution of providing safe drinking water for developing countries. They intend to do this by designing water well drilling equipment that is affordable to communities in a developing nation.

The stakeholders for this project are the San Luis Monday Rotary Club, WATERBOYS DRLG, and a potential entrepreneur or community in a developing country.

The San Luis Monday Rotary Club is motivated to invest financially into this project because safe drinking water is an essential component to healthy, thriving communities. Rotary International has long been involved with many types of similar projects to improve the living conditions of people in the developing world, thereby living by their motto, "Service above self." Compassion from these club members drives them towards supporting research and development for a more efficient drilling system over already existing systems. Furthermore, they hope to bring clean potable water to communities through water wells, after receiving affordable drilling equipment.

WATERBOYS DRLG justifies their participation in this project for similar reasons and will donate their engineering effort for developing third world health solutions.

The goals for this project are:

- To design and construct a low-cost drilling equipment that is maintainable and serviceable using parts readily available in the developing world that is powered by human muscle strength
- The drilling rig must be transportable
- The drilling rig must be able to drill to depths of 75 to 100 feet through alluvial soils
- The cost of drilling each well should be no more than $500

BACKGROUND

Throughout the developing world, impoverished countries such as Rwanda and Zambia, the large majority of residents do not have access to convenient and sanitary water supplies. This creates many problems in regards to the health and quality of their daily life. People in the developing world need access to water to stay healthy, hydrated, and for agricultural purposes. Without access to clean water residents rely on unsanitary water conditions that increase the risk of water born diseases and wreak havoc on the local populations.

Providing local residents with a system for developing water wells will allow them to have water and a means to construct multiple wells at a very low cost. This low technology system would also provide a means to stimulate the local economies of the impoverished communities. Local workers would be employed directly and indirectly through such a project, from drilling the well, providing maintenance and support roles, transporting water to the places that need it most and allowing other members of the community to spend time with important tasks such as taking care of families and going to school. Besides the physical benefits, the workers would see emotional benefits and connections to the community by providing a necessary and vital resource to their fellow people.

The goal for this project is to design a drilling rig that can access available ground water in developing nations. The ground water to be accessed by the drilling equipment is stored in underground pockets called aquifers. These aquifers are reliable sources of water that are generally cleaner than the water that is currently available. Wells can be dug using a variety of simple methods that can be applied to rural areas; those methods are hand dug, bored, jetted, rotary, driven and cable tool wells. Each techniques has their own application to different types of drilling medium, capable depth of well, and ease of use. Whichever method is chosen, there will be a hand pump attachment to facilitate the gathering of water from the open hole, which exposes the aquifer.

When considering the types of material to be drilling through in order to access the ground water below there are problems that need to be taken into account when determining how to drill into the aquifer and which technique to use. These problems are cutting the formation, which type drilling system to use, which type of bit to remove material, how to maintain borehole stability, how to run the casing, and how to install the water hand pump.

Through initial research of the drilling systems that currently exist to provide clean, potable, and usable water to rural, impoverished countries there were many that fit the description and characteristics required by our sponsor. The general requirements are: transportable, simple design, and low weight. There are also specific drilling requirements: simple drive, different methods to install casing and drill cutting removal. A detailed option ranking system can be seen in the attached House of Quality, which ranks options based upon a level of satisfaction for specific design requirements.

Current competitors to WATERBOYS DRLG are the Rockmaster TX 450 and the Life Water LS-100. Both of the drilling models use a small engine with a power range of 4-6 hp. The LS-100 model is a rotary drilling system that weighs in at 850 lbs and can be easily maintained, taken apart, and transported to the rear of a trailer or animal. The LS-100 is inexpensive and currently used around the world in impoverished areas. With two different bit sizes, 6” and 4”, the LS-100 is compatible to three types of bits in order to drill through alluvial and rock medium.

Rockmaster’s TX 450 is powered by a Briggs and Stratton motor that has the capability to produce drilling rates up to 2 minutes per foot. This system is inexpensive and can drill wells up to 8” diameter. The TX 450 drills up to 100 feet in depth and stands at a height and weight similar to the LS-100. With high strength material parts, the TX 450 is lifetime warranty on the drilling parts and frame.

Although the competitor’s drilling equipment is affordable and high quality, it will be advantageous to design a drilling rig that will be human powered. One factor to consider is the lack of fuel and motor availability in developing nations. A human powered drilling rig can be designed to be lightweight, affordable, simple in design, easy to maintain, and transportable. By incorporating the ideas of existing competitor designs and allowing the rig to be human powered, a more ideal design is engineered.

OBJECTIVES

The overall goal of the project is to design, build, and test a drilling rig that is easily transportable, manually powered, can drill through alluvial soils and most importantly affordable to a community in a developing nation. The long term goal of the project is to make the drawings for the drilling equipment available on either the internet or through a local Rotary Club so that an entrepreneur in the developing world can create their own business of drilling wells, potentially stimulating the economy of the developing nation. The engineering specifications for the project have been derived from the customer requirements and a House of Quality, in the appendix.

Spec #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Drill Depth	100 feet	Max	M	A, T
2	Borehole Diameter	4 inches	Max	M	A, T
3	Drilling Equipment	Sand, Gravel and Clay	Min	M	A, T
4	Power	Manually powered	Min	M	A, T
5	Equipment Affordability	$2,000	Max	M	A, S, I
6	Well Affordability	$500	Max	M	A, S, I
7	Safety	3 people	Max	L	A, T, S, I
8	Manufacturability and Serviceability	Manufactured and serviced in developing nation	TBD	L	S, I
9	Transportability	50 lbs per piece	Max	L	A, T
10	Robust Design	10 wells	Min	M	A, S

Table 1 – Engineering Specifications derived from House of Quality as well as meeting with Tim Cleath on October 9th. Risk is the level of risk in meeting the requirement, L = Low, M = Medium, and H = High. For compliance, A = Analysis, T = Test, S = Similarity to Existing Designs, and I = Inspection.

Engineering Specification Discussion

Spec 1 – Drill Depth

The drilling equipment needs to be able to drill to a maximum depth of 100 feet through alluvial soils. This specification is derived from the customer's knowledge of the intended drilling area where the maximum depth of the water table is 75 to 100 feet. Drilling equipment currently exists that can reach a depth of 100 feet but our drilling system must be manually powered and the aforementioned are engine powered, which is why the risk is medium. Currently manually powered systems do exist that can drill to a maximum depth of 60 to 70 feet.

Spec 2 – Borehole Diameter

The drilling equipment must be capable of drilling a vertical hole to allow for a 4 inch diameter casing to be installed. Drilling equipment exists that has less than a 4-inch borehole diameter, which is why the risk is low.

Spec 3 – Drilling Equipment

The drilling equipment needs to be capable of drilling above and below the water table, through a sand, clay, and gravel without any degradation to borehole stability. The risk of meeting this specification is medium, because despite existing drilling equipment used in the developing world that drill through these same soil types, most are not manually powered.

Spec 4 – Power

The drill must be manually powered. This specification is derived directly from the customer's desire to make the drilling equipment as affordable, transportable, and available as possible. The risk of meeting the specification is medium; currently equipment exists that is able to drill wells manually but it is inefficient.

Spec 5 – Equipment Affordability

The drilling equipment needs to be affordable to a community in a developing nation, costing less than $2000. One of the goals of the project is to empower an entrepreneur in a developing nation to take the drilling equipment and create a business of drilling wells throughout the nation. By making the equipment affordable it will give a greater number of people access to clean drinking water. This is the first step in developing the community and increasing the quality of water and sanitation conditions, decreasing the prevalence of illnesses related to water and sanitation, which account for 80% of the illnesses in the developing world. The local community in the developing nation will purchase the equipment as a lease to own type of agreement. Currently all of the drilling equipment in use is either high cost and efficient but not easily transportable or low cost but inefficient. The goal of the project is to design a low cost, easily transportable, and efficient drilling rig but because of the uncertainties in the design currently the risk of meeting the requirement is medium.

Spec 6 – Well Affordability

The cost of drilling a well must be affordable to a community in a developing nation, costing less than $500. At this price the customer predicts that communities will be able to invest in a well. As mentioned in the Equipment Affordability specification (spec 5) one of the primary goals of the project is to make the wells affordable making water available to the greatest number of people, which may help stimulate their economy. The major contributors to the high cost of well are renting the drilling equipment and the cost of the pump. The project’s aim is to reduce the cost of the equipment by designing the complexities out of the equipment. Due to the degree of uncertainty in the design, at this point, the risk of meeting the specification is medium.

Spec 7 – Safety

The customer does not want to cause any bodily harm on the people of the community, so the equipment will be designed with safety in mind. One way for the equipment to be safe is to reduce the number of people operating the equipment to a maximum of three. The operation of the drilling rig will not require the operator to perform any unsafe practices, and all moving parts will have sufficient clearance to prevent trapping or pinching the operator during use. Also the drilling rig will be designed to be stable in its erect position during assembly and operation. The risk of meeting this specification is low based on current equipment in use.

Spec 8 – Manufacturability and Serviceability

The drilling equipment must be manufactured and serviced in the developing world with readily available parts and materials. The project’s ultimate aim is to empower the local people and stimulate their economy, one way to do this is to put them to work building and servicing the drilling equipment. By using their local tools and materials it will allow them to become less dependent on foreign countries, which is related to the Equipment Affordability specification (spec 5). Standard fabrications techniques will be available such as welding and brazing equipment in most of the communities where the drilling equipment will be used, the risk of meeting this requirement is low.

Spec 9 – Transportability

The drilling equipment needs to be easily transportable, meaning it must be able to be broken down into pieces that weigh a maximum of 50 lbs each. This specification is from the customer's desire to have the equipment reach as many people as possible and the extreme case of this is carrying or flying the drilling rig into a community on the poorly maintained roads or trails. Based on equipment currently available the risk of meeting this specification is low.

Spec 10 – Robust Design

The drilling equipment must be able to function with minimal maintenance for a minimum of 10 well drilling operations. The robust design of the drilling equipment is related to the Equipment Affordability specification (spec 5) and the customer's desire to empower the local people. The risk of meeting this specification is medium due to the uncertainty in the drill system design currently but may risk may be lowered throughout the project.

DESIGN DEVELOPMENT

The drilling equipment must be able to cut through the formation, clean the cuttings from the borehole, and prevent the borehole from collapsing.

Well Drilling Methods

There are three major types of drilling systems that apply to the task of accessing groundwater in third world countries in alluvial soil formations. Those types of systems are:

- Hand dug wells – Where all of the excavation is performed by one or more men down-hole
- Human Powered Drilling Systems – Where a conventional method of drilling is run with men operating the rig on the surface
- Portable Drilling Rigs – Which are mechanically powered, usually by a gasoline engine

The goal of this project is to design and create a human powered drilling system that is applicable to third world countries in alluvial soil formations. From this requirement, the third type of system, portable drilling rigs, is ruled out of consideration. Before determining which type of drilling system to employ, an in-depth research was conducted on what is available and currently used. Those methods of drilling are:

- Hand Dug Wells
- Cable Tool Drilling
- Hand Auger Drilling
- Sludging
- Rotary
- Hybrid – Rotary & Percussion

The following is a brief synopsis of the advantages/disadvantages/and applications of each of the systems found during out preliminary research.

Hand Dug Wells

Digging wells by hand was the conventional method to obtain water in developing countries, before mechanical equipment became available. Figure 1 on the right shows a typical example of a hand dug well site. The disadvantages of hand dug wells are that they are restricted to suitable types of

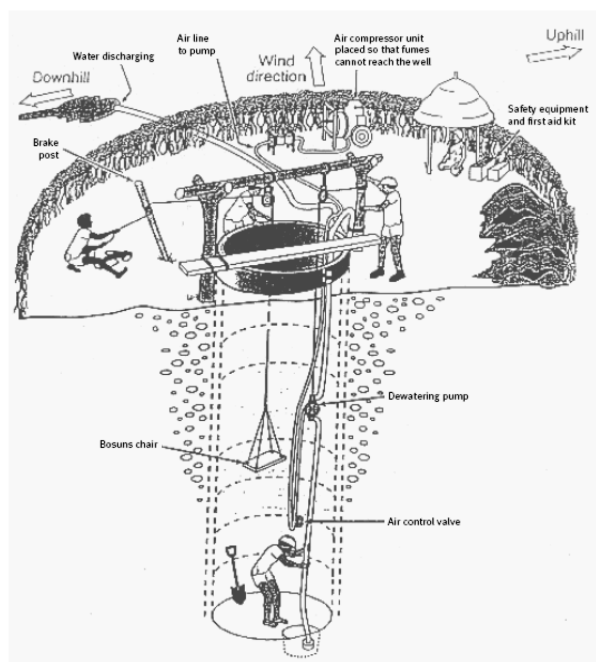

Figure 1: Hand Dug Wells

soil, and in order to reach the water table the sides of the hole need to be supported. Also the well requires a person, sometimes children, to be digging down-hole, exposing them to the frequently occurring danger of having the hole cave-in. Because the wells are hand dug it takes much longer to complete construction and the wells are not able to reach anywhere below the water table so the wells frequently dry up.

The advantages of hand dug wells are that they are applicable to many different climates and formations, and require no existing technology. This allows for any size city or village to be able to create a well at virtually no expense, since labor is cheap. The ground is broken apart by hand tools, e.g. shovels, awls, etc, and sometimes explosives. In hand dug wells the hole is cleaned with a bucket and a rope lift and the hole is supported by a permanent lining that allows the digger to be down-hole.

Cable Tool Drilling

A type of percussion drilling, see Figure 2, cable tool drilling involves lifting and dropping a cutting tool attached to a cable from a stand. The resulting impact breaks up the formation and allows for the material to be removed from the hole using bailers. Depending on the rock formation, depths of hundreds of meters can be reached using cable tool drilling.

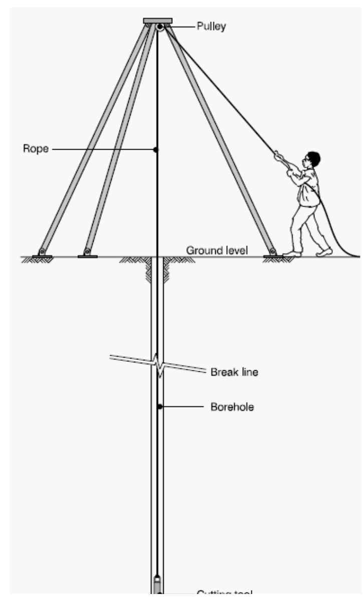

Figure 2: Cable Tool Drilling

The advantages of cable tool drilling are that the system is simple to build, operate and maintain. The system is applicable to many different types of soils and allows for drilling to be achieved below the water table. This allows for more of the water reservoir to be accessed by the well. As stated before, it is possible to drill to very deep depths with cable tool drilling.

Disadvantages to this system is that the equipment can be heavy, which puts a burden on the transportation and assembly of the system. Also, it is slower than some other existing methods. With percussion drilling, borehole stability can be an issue but temporary steel casing can be used to solve this problem, or also the use of a drilling mud has been known to prevent the open hole from collapsing through hydrostatic pressure.

Hand Auger Drilling

Similar to how a hole is drilled into wood, hand auger drilling consists of cutting the material from the bottom of the cutting tool by rotation and with that same rotation brings the cuttings of the open hole to the surface, seen in Figure 3. When the auger has cut into the ground, it is then withdrawn to remove the excavated material.

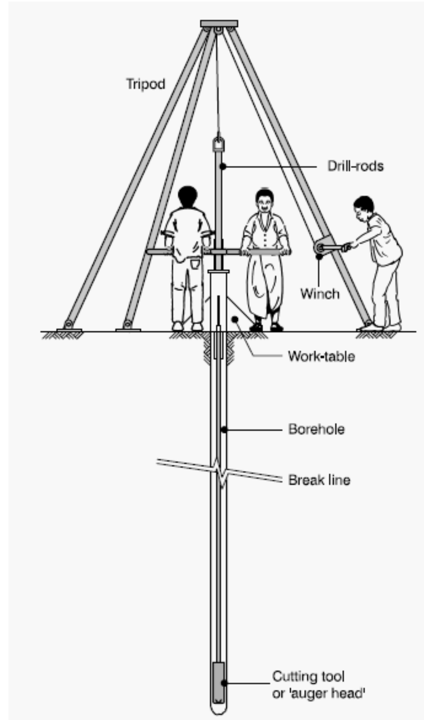

Figure 3: Hand Auger Drilling

Advantages to hand auger drilling are its simplicity, repetitiveness, ease to maintain and its low price for purchase and operation. The disadvantage of this system is its slow drilling speed when compared to other methods. The equipment can be heavy, which increases travel and set up time. Augers also have difficulty when trying to cut through rock and when a dry hole is encountered water is needed to facilitate the cutting and removal of cuttings. The opening is supported, if necessary, by temporary plastic and steel casing.

Sludging

Also known as hydraulic percussion or reverse jetting, sludging, see Figure 4, uses water pressure down-hole to remove the formation. Developed in Bangladesh, a hollow pipe of bamboo or steel is moved up and down in the open hole while a one way valve provides the pumping action. Water flows through the pipe and down the borehole and back through the annulus of the hole carrying the cuttings of the formation with it. This method requires a reservoir for the drilling fluid recirculation.

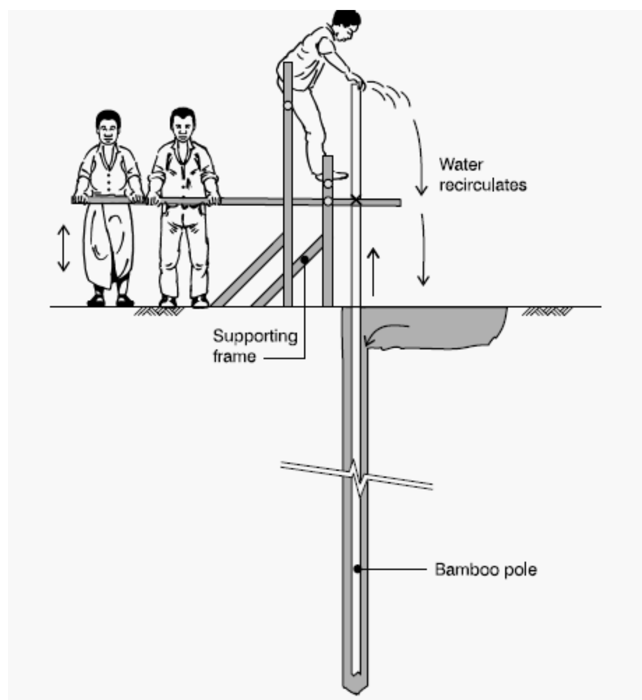

Figure 4. Sludging

The advantages to sludging are that materials to create such a system are readily available, low cost, and simple to use. The disadvantages are that water is required for pumping and it can only drill through unconsolidated formations; large rocks and boulders can prevent further progress. The water is required both to remove the material from the open hole and maintain borehole stability.

Rotary Drilling

Currently used in some third world countries under the name LS-100, rotary drilling uses motorized rotation to rotate a drill pipe and bit to cut the rock and formation. The cuttings are then removed through circulation of drilling fluid. This drilling fluid also keeps the borehole open with hydrostatic and dynamic pressure as it circulates the cuttings to the top.
The advantages of rotary drilling are the variety of rock formations that can be drilled and how the drilling fluid facilitates drilling in unconsolidated formations by keeping the borehole open. Rotary drills are also able to drill to very large depths. The disadvantages of this system are that it requires a capital budget to purchase such a rig and due to the technology involved it requires careful operation and maintenance.

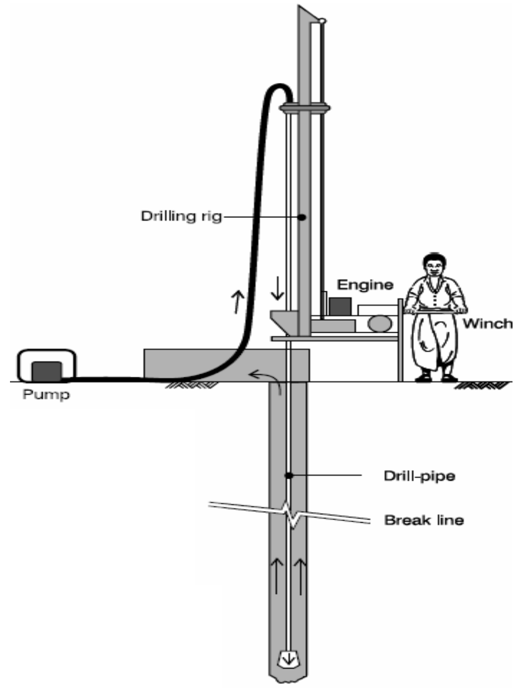

Figure 5: Rotary Drilling

This rotary type rig, the LS-100, is what we are trying to replace with our human powered design.

Hybrid- Rotary and Percussion

This hybrid drilling system is a combination of rotary and auger drilling and cable tool percussion. This system would have a combo auger/cutting tool to break apart the formation with percussion and then the augered cutting tool would remove more of the formation. This system would ideally combine the best of both drilling systems and expedite the drilling process. The advantages to this system would be that more material would be removed per stroke of the percussion tool and the total depth of the well would be reached faster. Also, the

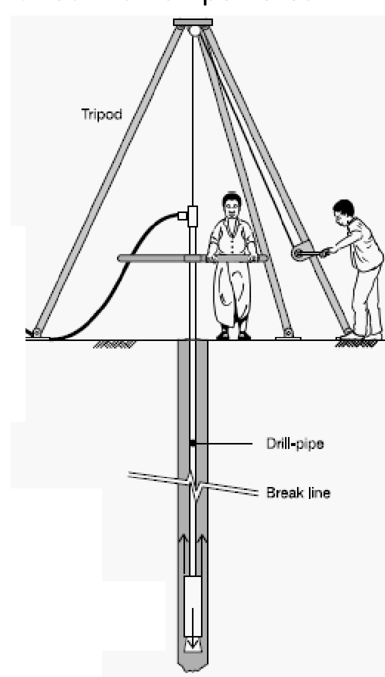

Figure 6: Hybrid - Auger Percussion

drillers would be able to drill way beyond the water table and increase the life of each well dug.

The disadvantages to this system however are that it would require a larger borehole than either of the systems alone; this larger borehole would have to compensate for the cutting tool that is a hybrid between an auger and percussion instrument.

Decision Matrices

Drill System

To quantitatively determine which drilling system is best suited for this application a comparison has been done between several of drilling systems, many of which are currently used in developing nations. A full description of each type of drilling system is given in the well drill methods section above.

From the decision matrix it is apparent that the cable tool, sludging, or hybrid type drilling system are the systems that should be pursued in the preliminary design. Important observations from the decision metric are:

- The capital cost of each drill system is difficult to determine, since no detailed design has been complete, but based on research the rotary drill system cost is similar to that of the hand dug well due to the high cost of the pumps needed to circulate the drilling fluid (Worth, 1998).
- By design, each drilling system will require no more than three men to operate, which is why there is no deviation from the datum.
- The rotary drilling system is more complicated than the other systems because of the greater number of moving parts and the need for a pump for the drilling fluid. This is a disadvantage due to an increased risk of breaking a component and initial capital cost.
- Each drilling system is much safer than the nominal comparison, hand digging a well, because there is no one in the in the hole directly. More importantly, there is a decreased risk of contaminating the well's water supply after completion of the well.
- The power needed to operate the drilling system is very important because of the limited amount of human power available. The cable tool and sludging methods will require less power to operate than the rotary, auger, and hybrid systems because with these method use gravity to pulverize the soil.
- The sludging and auger system are currently being used but they are limited by the depth of the water table and by the types of soils being encountered. The cable tool system is effective in the soil types that will be encountered but it may be slower than

other methods (Shaw, 1998). Also, if borehole stability is a concern use of a temporary steel casing will be needed for the cable tool method.

Overall, the cable tool and hybrid type drilling system are the clear choices based on this decision matrix, conversations with Tim Cleath, and other research. The sludging method does not meet the design requirements of drilling through gravel, so it can be eliminated as a choice. Whichever drilling system is chosen, the design will start from the bit up. Once the weight of the bit and bit driving forces are determined the drilling rig can be designed around it.

Criteria	Weight	Rotary	Cable Tool	Auger	Sludging	Hand Dug	Hybrid
Capital Cost	**5**	0	1	1	1		1
Per Well Cost	**5**	0	1	1	1		1
Number of men required to operate	**2**	0	0	0	0		0
Simplicity of design	**2**	-1	1	1	1		0
Safety	**4**	1	0	1	1		1
Ability to Maintain Borehole	**5**	1	0	-1	1		0
Efficiency	**2**	1	1	0	1		0
Manufacturability	**4**	0	1	0	1		0
Power needed to operate	**4**	-1	1	-1	1		-1
Performance in Clay	**5**	1	1	1	1		1
Performance in Sand	**5**	-1	1	1	1		1
Performance in Gravel	**5**	0	1	-1	-1		1
	Sum Minus	-3	0	-3	-1		-1
	Sum Plus	4	9	6	10		6
	Sum	1	9	3	9		5
	Weighted Sum	5	37	12	36		25

Table 3: Above is a decision matrix comparing the various types of drilling systems discussed earlier. The criteria were derived from the design requirements, discussed in the objectives section. The hybrid mentioned above would combine a cable tool percussion drilling system and an auger drilling system.

Drill Bit

The decision matrix for deciding which drill bit that will be most applicable to drilling in alluvial soils is seen below. From preliminary research, the various types of drill bits available were found and listed without any immediate discarding, despite how uncommon or unpractical the design. From the research of the drill bits and previous concerns from water well drillers and geologist spoken to, a list of important criteria for a drill bit design to satisfy was compiled. Those concerns are:

- Price – Especially important when providing a functional drilling system to third world countries/villages with little to no income
- Manufacturability – Must be taken into consideration when determining what tools and skills are at the disposal of the drillers in rural countries
- Availability – How easy the actual drill bit or the parts to repair or fix the drill bits can be made or delivered to the drill site and country of focus
- Ability to Cut Soil – The purpose of the drill bit is to drill the open hole in the soil for the swell casing
- Cutting Efficiency – How effective is the drill bit at removing soil as to not keep the drillers on one well for any longer than necessary
- Reparability – When the drill bit breaks under down hole conditions, will the drillers be able to repair the bit and continue drilling in the shortest amount of time

Below the decision matrix can be seen with each of the criterion and their specific weighting or ranking as to their importance in making the decision of which type drill bit to use. The types of bits were compared to a datum, which is the current type used in drilling water wells and their respective scores were summed to determine which bit should be chosen to look into after preliminary design work.

Criteria	Weight	Purchased Bit	Component Bit	Machined Bit	Arrowhead Bit	Auger	Straight Cone	Feeler Teeth / Scratch
Price	**2**	-1	0	0		0	1	0
Manufacturability	**2**	-1	0	-1		0	1	0
Availability	**2**	-1	0	0		0	1	0
Ability to cut soil	**3**	1	1	1		1	-1	-1
Cutting efficiency	**3**	1	1	1		1	-1	-1
Reparability	**1**	-1	0	-1		0	0	0
	Sum Minus	-4	0	-2		0	-2	-2
	Sum Plus	2	2	2		2	3	0
	Sum	-2	2	0		2	1	-2
	Weighted Sum	-1	6	3		6	0	-6

Table 2: Drill bit decision metric, preliminary drawings of each drill bit can be seen in the appendix.

From this decision matrix, it is apparent that the component bit and auger yielded the highest weighted sum above the current method.

Being a simple design, the component bit and the auger will have the same price for each as they can be made from simple materials on site and by a machine shop. This low price ties into their ease of manufacturability, with no definite type of material necessary these types of bits can be made by a skilled laborer without much experience; this characteristic makes it ideal for third world drilling sites. Also, since the parts and assembly of each bit is relatively simple, replacement bits can be attainable relatively quickly. The next part of the characteristic criterion deals with how the bit performs.

Each bit has the ability to cut the soil was compared, and the component bit and auger bit scored with equal high marks. From research into bit design, speaking with current drillers and reviewing actual drilling practices it was determined that these two designs perform well when removing material. The component bit is a design that is a derivative of the arrowhead bit (the currently used type) that has the ability to change the way it cuts the formation based upon the type of soil/material the well is in. This is a key part of requirements set forth by the sponsor, as the drilling cuttings are to be monitored and checked after each drilled foot. By adapting the bit to the circumstances, the drilling system will perform better. The auger style bit not only removes the soil, but it also pulls itself deeper into the open hole while forcing the cuttings to the top. This system has been seen by the system design team and also satisfies the sponsors' needs of drill cutting monitoring. The cutting efficiency of each of these drill bit types is proven through the extensive use of each in cable tool drilling and rotary/auger drilling.

It was not surprising that both of these options scored the highest marks in the decision matrix, as they have both been tested for centuries. Also, the team has thought of combining a cable tool and auger system. This type of drilling system will be talked about in the Drilling System section of design development. Pictures of each of the type of bit can be seen in the appendix.

Power System

To determine which type of powering system is best suited for this application a comparison has been done between several powering options both human and non-human powered. Some of the methods are in use in developing nations while others are ideas that seem feasible such as a hand or foot powered bicycle.

Criteria	**Weight**	**Hand Powered Bike**	**Foot Powered Bike**	**Pulley System**	**Engine**	**Car hub rotation**	**Manually twist**	**Animal Powered**
Potential Power	**4**	0	1	0	1	1		1
Length of sustained power	**3**	0	1	0	1	1		1
Implementation cost	**4**	-1	-1	0	-1	-1		-1
Safety	**5**	0	0	0	-1	-1		0
Applicability - would it work	**5**	1	1	0	1	1		1
	Sum Minus	-1	-1	0	-2	-2		-1
	Sum Plus	1	3	0	3	3		3
	Sum	0	2	0	1	1		2
	Weighted Sum	1	8	0	3	3		8

Table 4: Above is a decision matrix discussing the various methods that could be used to power the drilling equipment.

From the initial decision metric a bike or an animal should be used to power the drilling equipment. Using an animal is not feasible because some communities don't have animals capable of doing the work, so it will not be considered in the final design. Whichever powering method is chosen its design must minimize the number of pinch points and increase the comfort of the operator.

Casing

Criteria	Weight	Steel	Aluminum	Composite	Wood	Plastic	Cast iron
Cost	**3**		-1	-1	1	1	0
Strength: Fatigue and Max Stress	**2**		0	1	-1	-1	0
Manufacturability	**1**		0	-1	0	0	0
Availability of material	**2**		-1	-1	1	1	0
	Sum Minus		2	3	1	1	0
	Sum Plus		0	1	2	2	0
	Sum		-2	-2	1	1	0
	Weighted Sum		-5	-4	3	3	0

Table 5: Casing decision metric

After assessing the results, plastic casing is the best candidate for the casing criteria. Steel seems to lose most of its value as a candidate from factors of cost, and maintainability due to the corrosive properties and heaviness. Bamboo, although affordable, is highly demanding of skill and resources due to the intricate method involving bamboo wrapping. Coil tubing is more advanced in its technology than other systems, however, is high cost and has the same corrosive properties as steel. Although, the coil tubing is very strong in various measures, the method of installing coil tubing is rigorous and costly for materials. Hence, for the factor of cost, which happens to be a crucial factor, coil tubing loses much of its validity. The plastic casing is left to be the most desirable casing with low cost and sufficient strength and easy maintainability with a pump system.

Economics

In developing countries medium to small enterprises have difficulties receiving funds to efficiently scale up their businesses. There are many reasons for this but in general these individuals lack collateral and credit history needed to receive a loan. The loan amounts they need are only a few thousand dollars, which is not as profitable for a normal bank due to the high transaction costs of a loan. Also, there is a lack of access to efficient and cheap debt and equity markets like in the United States and other developed nations. The solution has been setting up microfinance intermediaries, who channel money from the lenders to the borrowers directly, collateral free but at relatively high interest rates 20% (Fernando, 2006). These small loans play a vital role in the economic development of the country and the economy, leading to the economic freedom of many. An example of this is the Grameen Bank in Bangladesh who has provided collateral free loans to women and men, allowing millions to effectively scale up their business and decrease the number of people in poverty. This same type of loan could allow a prospective entrepreneur in a developing nation to purchase the drilling equipment and begin to drill water wells throughout the country. The effect is twofold, it increases the country's access to clean safe drinking water while stimulating the economy by having a local workers manufacture, operate, and maintain the drilling equipment. The most difficult part of the venture is going to be the initial capital investment. In order to fund the capital investment an entrepreneur could get a loan from a microcredit institution in their country or they could have a lease to own agreement with a local Rotary club.

As mentioned in the previously, the drilling equipment will be designed to be manufactured, assembled, and maintained in a developing nation using available parts, materials, and engineering process. It is assumed that they have access to standard engineering materials and processes, such as welding, brazing, forging, drilling, and cutting.

Available Human Power

As specified in the design requirements the drilling system needs to be powered manually, e.g. powered by human or some other animal. From a NASA study an average "healthy man" can output a sustained 200 W (0.27 hp) for about an hour, see appendix for graph. For the design of the power system it will be assumed that there will be a constant 0.25 hp available to power the drilling equipment, assuming the people will switch off powering the equipment.

Hand Pump Selection

Hand pumps are selected based on the community's needs as well as the height the water needs to be lifted. For the intended drilling depth of the project, 100 ft, an intermediate to high lift pump is needed. These pumps are designed to reduce the amount of physical effort needed to pump water to the surface. The components have to be more robust than other pumps due to the large stresses created while pumping. A detailed cross section of the Afridev high-lift hand pump can be seen in the appendix. A concern during drilling is the verticality of the borehole; the borehole must be near vertical to ensure optimal hand pump efficiency, preventing premature wear of the components.

Soils

Soil will be critical to analyze for the purposes of the design process of any drilling equipment. The customer has determined the desired drilling medium to be unconsolidated alluvial soils. The term 'alluvial' refers to a condition of soil after a body of water has deposited sediment in a geological area. Grain types associated with alluvium consists of sand, gravel, and clay. Furthermore, the grain sizes vary depending on geologic location.

The customer has more specifically determined the top layer of the alluvium to be unsaturated and depending on the depth, saturation may vary.

Soil Strength Analysis

A soil strength analysis will be performed for the worst case soil condition: clay. It is assumed that if the drilling equipment can drill through clay is will be able to drill through sand, where the primary concern is borehole stability, and gravel, where the primary concern is extraction of the cuttings. Depending on the chosen drilling method the soil strength analysis will change. If the cable tool drilling method is chosen the weight of the tool needs to be determined. The compressive strength of clay is known to be 7.8 – $9.8*10^5$ N/m^2 and to calculate the cutting force available impulse and momentum equations will be used. If the hybrid drilling method is used, the above analysis will need to be performed for the cable tool component of the equipment as well as separate soil strength analysis for the auger component, to determine the necessary downward force on the auger bit to cut through the soil.

Soil Properties

A familiarity with each soil type from alluvial soils will be crucial. As the drill bit is lowered and in operation, the bit will bite, torque, and shear differently depending on each soil type. To be familiar with each soil type will be advantageous in the understanding of power demanded at the bit and the bit type in operation.

Soil Grain Types	Diameter (mm)	Hydraulic Conductivity K (cm/s)	Cohesive?
Gravel	**4.75 – 75**	10^2- 10^{-1}	No
Sand	**0.75 – 4.75**	10^0- 10^{-4}	Only at partial saturation
Clay	**0.002**	10^{-5}- 10^{-12}	Yes

Table 6: Comparison chart for the different soil types that will be encountered during drilling.

Drilling Fluid

During the drilling process, there is the strong recommendation of using drilling fluid when casing is not being driven simultaneous to the act of driving the drill bit. There are three possible fluids for the purposes of drilling. These three are known to be: bentonite clay and water, water without additives, and water with commercial products.

If water is used without any additives the immediate disadvantages is the inability to prevent caving in of the bore hole. In addition, water alone cannot prevent the gradual squeezing in of the borehole or plastic soils. For any use above the water table, water derives its strength from capillary forces and the resultant apparent cohesion. Below the water table water exerts a stabilizing effect on the parts of the borehole extending below the ground water level and temporarily increases the rate of swelling, but it decreases the ultimate amount of swelling of the soil in vicinity of hole

Because of the many disadvantages of using water without additives, the next possible alternative is using water with bentonite clay. This clay is native in many areas, and has a higher density than water. When circulated, the clay will lift cuttings, ranging in sizes from clay to small gravel, from the bottom of the borehole.

In addition to native clay types, commercial products are sold as well. Aquagel, Baroid, and Colox, are three products mentioned that may or may not be available in developing nations. These may be available when native clays are not, and may be denser than normal clays, and are used to lift coarser grained materials out of the bore hole.

Settling Pits

When drilling fluid is circulated, a constant supply of fluid is needed in the process. In order to keep a constant viscosity of fluid pumped to the drill bit, a settling pit may be necessary. In the design of a settling pit, the purpose is to contain any cuttings from the bore hole and recycle any drilling fluid. A trench is dug from the opening of the bore hole where circulated fluid overflows at the top. The trench leads the cuttings and fluid to a first dug pit. The cuttings settle to the bottom of this dug pit and the fluid is able to flow through a weir at the top in order to allow drilling fluid to collect in another pit where a pump collects the recycled fluid. This returns to the bottom of the bore hole for lifting more material.

Testing, Verification, and Validation

To ensure that the drilling equipment meets the design requirements a test well will be drilled in San Luis Obispo County, at a sponsor selected site. Also, during the test well drilling operation the assembly, safety, and maintainability of the equipment will be evaluated.

Schedule

Fall Quarter (ending 12/04/08)

- On Going Research - Aspects of Water Wells in Third World Countries
    - Types of Material (Alluvial Soil)
    - Applicable Drilling Systems
    - Drill Bit Information
    - Borehole Stability
    - Accessibility With Rural Locations
- Brainstorm Techniques for Dealing with Issues of Alluvial Soil
- Determine Characteristics of Drilling System
    - Material Removal
    - Bit Design
    - Mobility

Winter Quarter (ending 03/12/09)

- Testing of Specific Parts in Alluvial Soil (Cal Poly)
- Design of Prototype
- Manufacturing of Prototype

Spring Quarter (ending 06/04/09)

- Drilling of a test well
- Senior Design Expo
- Final Design Report

MANAGEMENT PLAN

From WATERBOYS DRLG, the team members are assigned responsibility as follows:

Brendan Ochoa

- Soil Analysis, Research, Documentation
- Casing Research, Implementation, Analysis
- Borehole Stability
- Developing Countries Geology
- Soil Strength Analysis

Matt Davis

- Power of drilling rig
- Total Equipment and per Well Cost
- Water quality standards
- Building and Manufacturing
- Economies of Developing Nations

Joe Engel

- Mechanics of the Drilling Rig
- Design of Drill Bit
- Building and Manufacturing

See Gantt chart in appendix for detailed project schedule.

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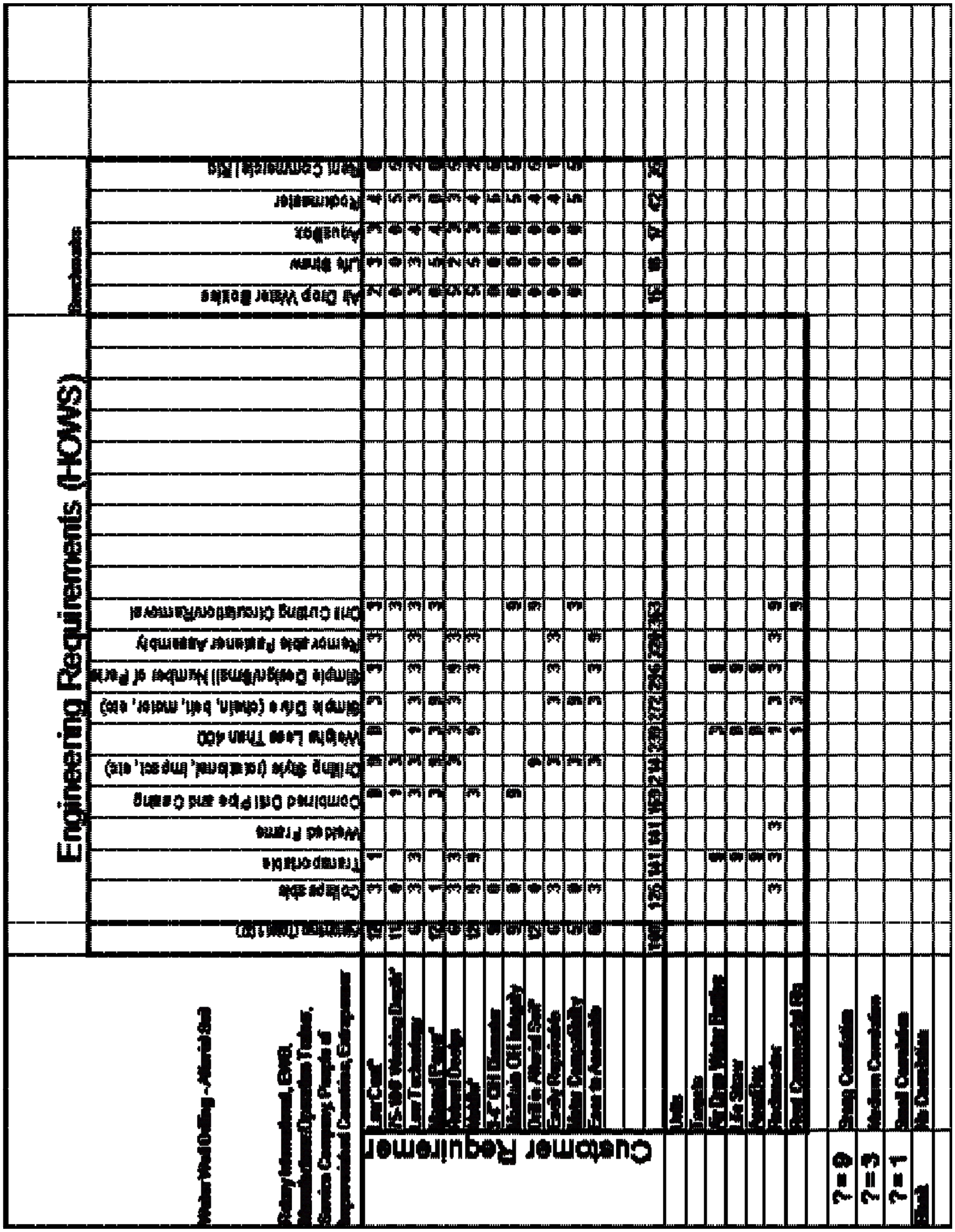
Appendices

House of Quality/QFD



Afridev Hand Pump

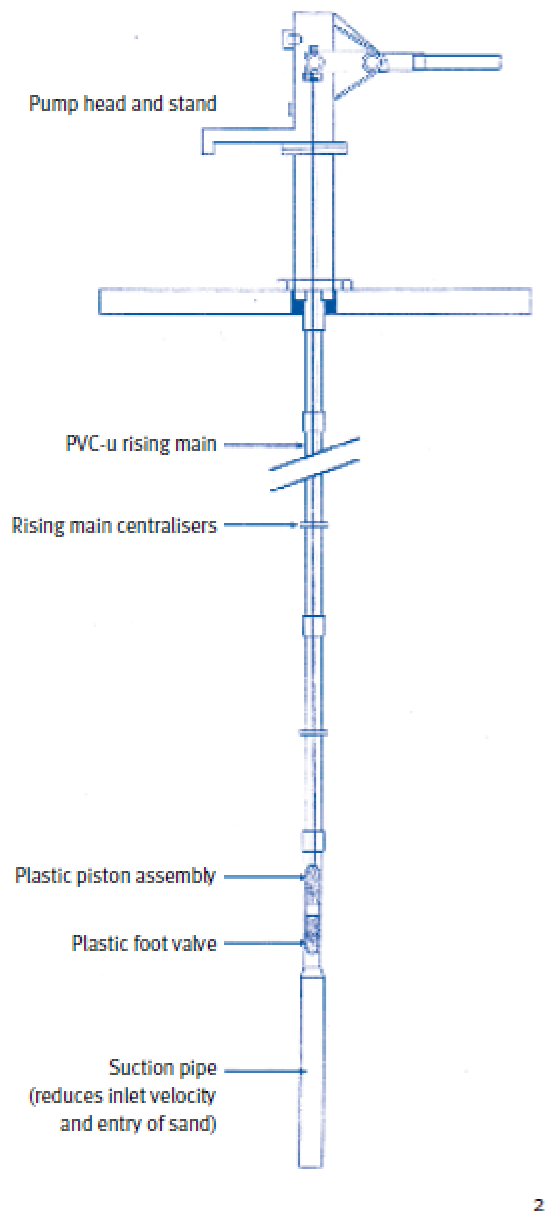


Figure 7: Cross-section of an Afridev high lift hand pump **(Aid, 2008)**

Human Power Curve Data

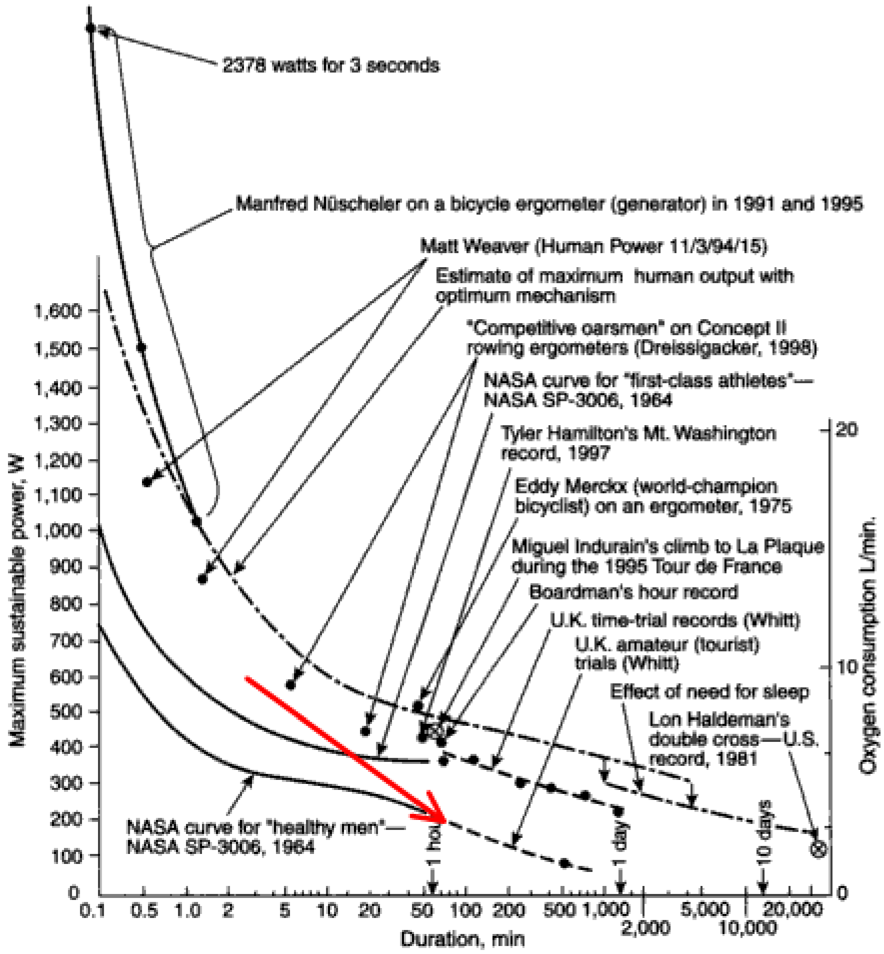
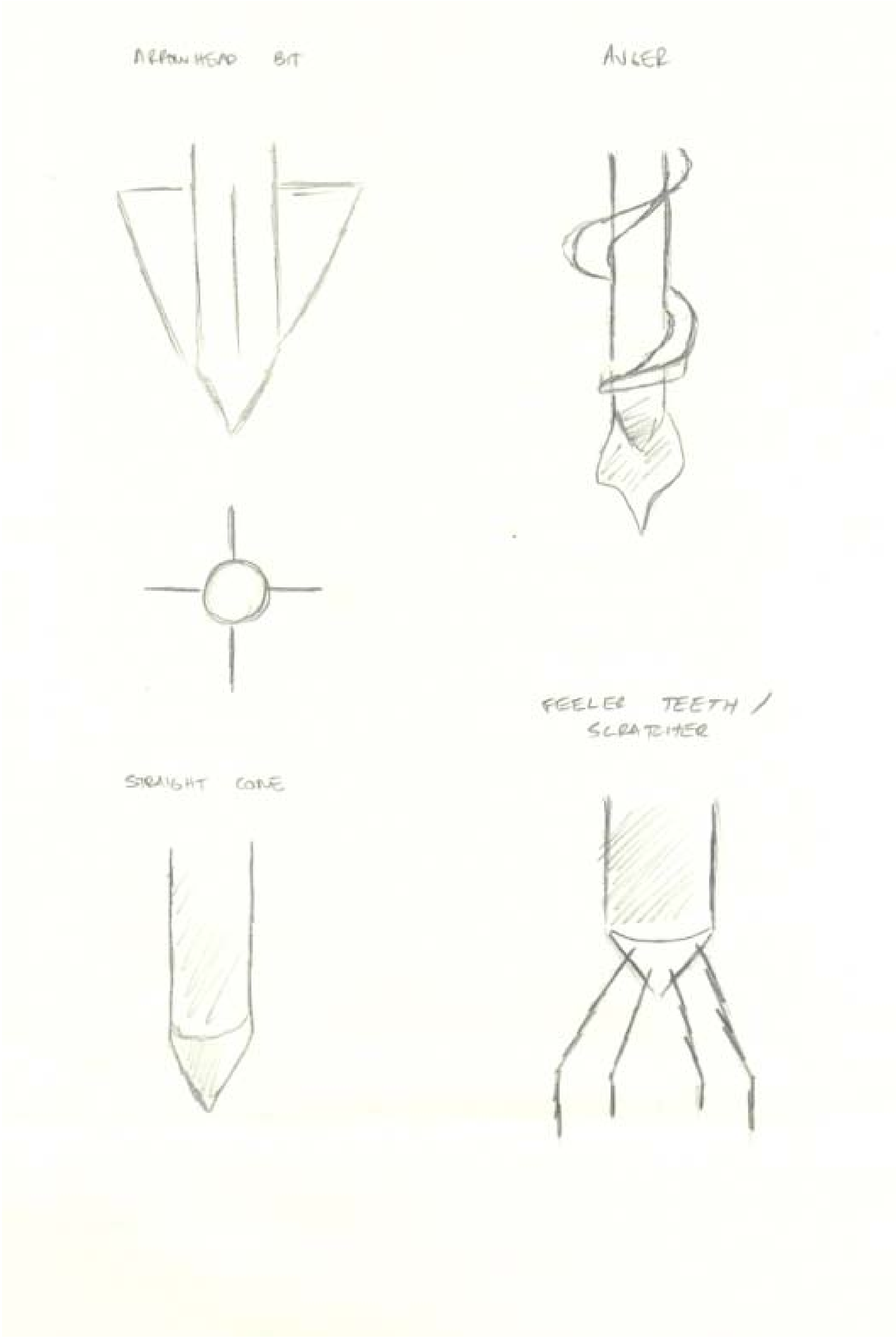
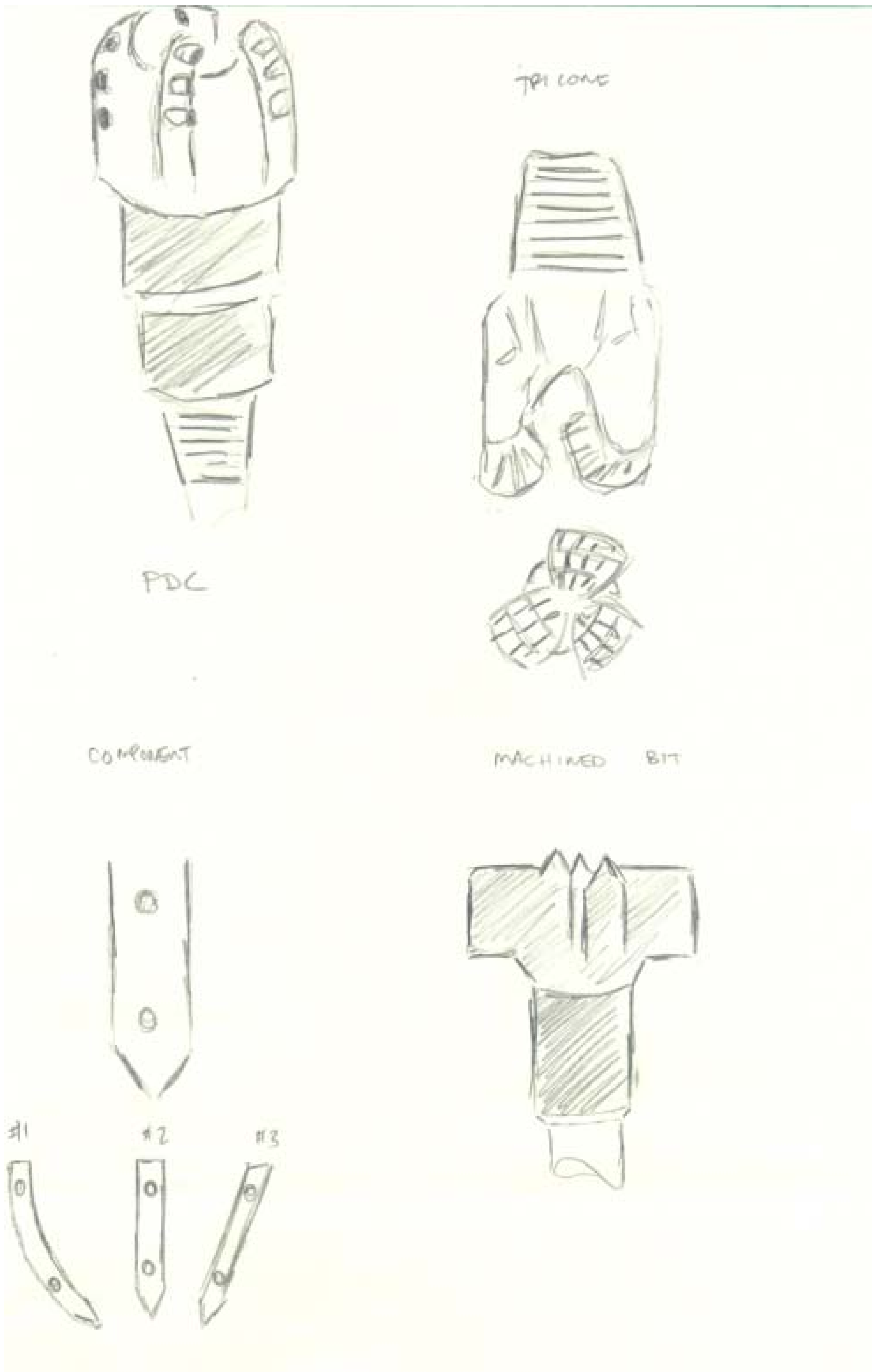


Figure 8: Average human power output, principally by pedaling, the arrow points to intended operation point (David Gordon Wilson, 2004).

Drill Bit Preliminary Design Pictures




TRI CONE
PDC
COMPONENT
MACHINED BIT
#1
#2
#3

Appendices

Gantt Chart

Task Name	Duration	Start	Finish	Predecessor	Baseline Team Hours				Actual Team Hours			
Senior Project Design	**183 days**	**9/23/2008**	**6/5/2009**		**Matt**	**Brendan**	**Joe**	**Total**	**Matt**	**Brendan**	**Joe**	**Total**
Consider Projects	1 wk	9/23/2008	9/29/2008		2	2	2	6	2	2	2	6
Report Writing - 2 hours per week	183 days	9/23/2008	6/5/2009		80	80	80	240	14	0	10	24
Project Familiarization	**11 days**	**9/30/2008**	**10/14/2008**	**2**								
Background Research	11 days	9/30/2008	10/14/2008		3	3	3	9	3	3	4	10
Develop Specification	11 days	9/30/2008	10/14/2008		2	2	2	6	2	2	3	7
Project Proposal Due	0 days	10/14/2008	10/14/2008		3	3	3	9	4	3	2	9
Project Research	**16 days**	**10/14/2008**	**11/4/2008**									
Soils	11 days	10/14/2008	10/28/2008		0	8	0	8	0	20	0	20
Drill Bit	16 days	10/14/2008	11/4/2008		0	0	5	5	0	0	7	7
Drilling Methods	16 days	10/14/2008	11/4/2008		10	5	10	25	8	0	5	13
Developing Country Economies	16 days	10/14/2008	11/4/2008		4	0	0	4	4	0	0	4
Drilling Rig	16 days	10/14/2008	11/4/2008		5	2	5	12	3	0	3	6
Drilling Rig Transportation	16 days	10/14/2008	11/4/2008		2	0	2	4	1	0	1	2
Drill System Selection	6 days	11/5/2008	11/12/2008	7	2	2	2	6	2	0	2	4
Drill System Design	**6 days**	**10/28/2008**	**11/4/2008**									
Bore Hole Stability	6 days	10/28/2008	11/4/2008		3	6	3	12	0	4	2	6
Drill Bit	6 days	10/28/2008	11/4/2008		2	0	8	10	0	1	5	6
Power System	6 days	10/28/2008	11/4/2008		8	0	4	12	0	0	0	0
Drilling System	6 days	10/28/2008	11/4/2008		10	5	10	25	0	0	2	2
Component Preliminary Design Reviews	**11 days**	**11/4/2008**	**11/20/2008**	**15**								
Bore Hole Stability	0 days	11/4/2008	11/4/2008		1	1	1	3	0	0	0	0
Drill Bit	0 days	11/11/2008	11/11/2008		1	1	1	3	0	0	0	0
Power System	0 days	11/18/2008	11/18/2008		1	1	1	3	0	0	0	0
Transportation	0 days	11/19/2008	11/19/2008		1	1	1	3	0	0	0	0
Drilling Rig	0 days	11/20/2008	11/20/2008		1	1	1	3	0	0	0	0
Drilling System Preliminary Design Review	0 days	11/21/2008	11/21/2008		1	1	1	3	0	0	0	0
Interim Design Report	0 days	11/6/2008	11/6/2008		6	6	6	18	0	5	9	14
Draft Design Report	0 days	12/5/2008	12/5/2008	27	6	6	6	18	0	0	0	0
Preliminary System Design Review with Sponsor	0 days	12/8/2008	12/8/2008	28	2	2	2	6	0	0	0	0

Task Name	Duration	Start	Finish	Predecessor	Baseline Team Hours				Actual Team Hours			
Design Refinement	**36 days**	**12/8/2008**	**1/27/2009**	**26,27,29**								
Evaluate Sponsor Feedback	21 days	12/8/2008	1/5/2009		3	3	3	9	0	0	0	0
Drilling System Review	0 days	1/15/2009	1/15/2009		2	2	2	6	0	0	0	0
Draft Design Report	0 days	1/22/2009	1/22/2009		6	6	6	18	0	0	0	0
Design Review	0 days	1/27/2009	1/27/2009		2	2	2	6	0	0	0	0
Final Design Report	0 days	2/3/2009	2/3/2009	30,28	6	6	6	18	0	0	0	0
Critical Design Review	0 days	2/5/2009	2/5/2009	35	2	2	2	6	0	0	0	0
Building and Fabrication	**53 days**	**2/5/2009**	**4/20/2009**	**36**								
Part Procurement	40 days	2/5/2009	4/1/2009		8	8	8	24	0	0	0	0
Drilling Rig Fabrication	0 days	4/20/2009	4/20/2009	38	10	10	10	30	0	0	0	0
Manufacturing and Test Review	0 days	4/20/2009	4/20/2009	37	2	2	2	6	0	0	0	0
Testing	**20 days**	**4/21/2009**	**5/18/2009**	**40**								
Assmebly	6 days	4/21/2009	4/28/2009		9	9	9	27	0	0	0	0
Transportation	6 days	4/21/2009	4/28/2009		4	4	4	12	0	0	0	0
Drilling Rig	6 days	4/27/2009	5/4/2009		2	2	2	6	0	0	0	0
Drilling a well	11 days	5/4/2009	5/18/2009		5	5	5	15	0	0	0	0
Test Review	0 days	5/18/2009	5/18/2009	41	2	2	2	6	0	0	0	0
Senior Design EXPO Poster Design	12 days	5/20/2009	6/4/2009	46	5	5	5	15	0	0	0	0
Senior Design EXPO IV	0 days	6/4/2009	6/4/2009	47	2	2	2	6	0	0	0	0
Final Project Report	0 days	6/5/2009	6/5/2009		6	6	6	18	0	0	0	0
				Totals	**226**	**208**	**229**	**663**	**43**	**20**	**2**	**65**