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HEIFER WELL PROJECT

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

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Degree of Bachelor of Science

by

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Abstract

A well site was designed for Heifer International's Overlook Farm. The site resembles one that would be found in a developing country. The purpose of the well site is to educate the public about the global water situation (pollution and scarcity). Research was done on wells and the global water situation.

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Problem Statement

Heifer International asked us to design a working well for their Overlook Farm, at the center if its global village, that would serve to educate the public about the global water situation. They expressed a desire for a low-tech well that will remain true to the minimalist theme of their global village. Our ultimate goal was to provide Heifer with a detailed design of the well and its surrounding area, as well as information on how to construct it. In addition, we gathered a great deal of information concerning water and wells, which we gave to Heifer for educational use.

In order to determine the most appropriate design structure for the planned well, we first collected several different types of data. The first type of data we collected includes information about the well site and its surroundings. This data included the location and size of the aquifer, the materials making up the aquifer, the materials present in the soil, and the quality of the water in the aquifer. This data helped us to reduce the number of possible design structures by eliminating the options that could not physically work at this particular location.

Since the ultimate goal of the well is to inform the public, we believed that it would be very beneficial if we first determined the extent of the knowledge that the public has regarding the global water situation. With this information, we were more able to clarify or debunk the myths and inaccuracies found in public opinion. To gather this data, we had decided that a survey would be most effective.

The third type of data we collected was in the form of a focus group interview. The objectives of this interview were to determine what the well could provide that would be appealing to its audience and different ways in which the public could be involved in the use of the well. We believed that the well would receive more attention if it offered something appealing to its audience. We also believed that its audience would be more likely to understand the significance of the global water situation if they were involved in the use of the well.

Once all of the data had been gathered, we chose 3 different possible design structures for the well. Heifer International then selected one of the three structures. At that point, we gathered all the information that was needed to begin construction of the well. Our goal was to give Heifer enough information that they would be able to begin construction immediately.

Literature Review

1. Heifer Project International

1.1. About HPI

Heifer International is a non-profit organization dedicated to the eradication of world hunger and poverty. By taking the ancient phrase into practice, "give a man a fish, feed him for a day; teach a man to fish, feed him for a lifetime," Heifer is able to lift poor and hungry families onto their feet, and set them on a path that allows them to ultimately become self-reliant. These families, in turn, then pass on this wonderful gift to other needy families in their community, setting in motion a chain of events that can potentially lift an entire community out of poverty. The Heifer gift is truly a gift that keeps on giving.

Heifer International combats world hunger and poverty by donating 'gift animals' to poor and hungry families throughout the globe, in addition to providing them with the knowledge needed to properly raise the animal and maximize the possible benefits, both for themselves and their community. These animals serve as an indirect, rather than direct, source of food and income by providing the family with milk, eggs, plowing power, and even companionship. With these animals, families have a virtually unlimited supply of nutrition that would otherwise be non-existent. By selling the benefits the animal provides, families earn income for education, health care, and shelter.

The families to whom Heifer International gives aid agree to sign a contract to donate their gift animal's first female offspring to another needy family in their community, called "passing on the gift." This is the fundamental principle of the organization that allows its gift to continue to affect the lives of the poor and hungry for years to come, saving the lives of entire communities through the donation of a single animal.

Heifer International has three learning centers in the United States, including the Overlook Farm in Rutland, Mass. These learning centers are designed to educate the public on issues such as world hunger, poverty, and environmentally-sound solutions (Heifer.org, 2003).

1.2. Overlook Farm

Heifer's Overlook Farm is a 270 acre working farm located in Rutland, Massachusetts. In addition to all the common characteristics of a farm, it consists of a global village of eight small sites (though some have not yet been completed) designed to resemble the communities to which Heifer provides aid, including Thailand, Peru, Guatemala, Tibet, Kenya/Uganda, Poland, India, and Maine. Each site has a humble dwelling and an animal pen, while many of the sites have additional points of interest (Heifer.org, 2003).

The Overlook Farm's most appealing characteristic is its atmosphere, which cannot be accurately described in words, though the word 'peaceful' could begin to characterize it. Its staff, volunteers, and visitors are the last of a dying breed of caring, hard-working men, women, and children, willing to work for a greater cause without expecting anything in return.

2. Water

Water is becoming a topic of increasing concern among environmental researches. All cultures on earth, though some more than others, suffer from water-related problems. With the global increase in industry has come a degradation of water quality and availability, and many believe this will continue long into the future. As freshwater sources around the world are running dry, more and more are coming to the realization that the global water situation is getting worse each year. Many cultures have to compete with their own industry for drinking water. Those that have water are fighting and losing a constant battle of health against the ever-increasing pollution problem. These problems will not go away on their own. As each day passes, closer and closer comes the time when all living beings on Earth will have to compete for a drink.

2.1. Vocabulary

2.1.1 Aquifer

An aquifer is an underground water reserve, usually composed of water-bearing rocks. They are an ideal source of water for many wells, especially those used in irrigation, because farmers can pump groundwater from aquifers at any time. "Compare this with the standard scenario for irrigating with river water: river flow is erratic, so a reservoir is usually required to store flood water for use in the dry season. And reservoirs … can lose 10 percent or more of their water to evaporation. In addition, the large canal networks that move water out of reservoirs are often unreliable – they may not deliver enough water when farmers actually need it. (Postel, 1999, p. 31)" Aquifers, in contrast, have a fairly slow and steady flow that is typically available year-round and there is no water loss due to evaporation. Also, groundwater is generally less expensive to develop than river water.

Aquifers are replenished through a process called recharge. This usually occurs naturally as part of the hydrologic cycle when rainfall infiltrates the land and drips into the underlying aquifer. In some cases artificial recharge is used by pumping water directly into the well or spreading water over the land surface above the aquifer. Some aquifers, known as fossil aquifers, are non-renewable, meaning they can not be recharged naturally or artificially. These fossil aquifers are typically thousands (perhaps millions) of years old and are found in arid climates that were once much wetter.

2.1.2 Hydrologic Cycle

The hydrologic cycle is a constant and unending circulation of Earth's water. Water can be stored in all three of its natural physical states during this cycle – liquid, ice, and water vapor. Ninety-seven percent of the world's water is held as liquid in the oceans. Polar ice sheets and glaciers account for about 2%. Groundwater amounts to about 0.6% and surface water in rivers and lakes amounts to about 0.1%. The remaining fraction of water is held in the atmosphere as water vapor. "The total amount of water on the earth's surface does not change; it is merely recycled through its three different natural states." (Design and Construction of Water Wells, 1988, p. 1)

The hydrologic cycle begins with condensation, which occurs when the temperature of the air or earth changes, causing water vapor in the atmosphere to form clouds. When the clouds can no longer hold the moisture, they release it in the form of precipitation, such as rain or snow. After precipitation, there are a number of possible paths the water can take. Interception occurs to water that falls on trees or vegetation, never reaching the ground. Infiltration occurs when the precipitation seeps into the ground. If the precipitation falls faster than it can infiltrate the ground, it becomes runoff, which flows into streams, rivers, and eventually large bodies such as lakes or oceans. Throughout this entire process the sun is continually causing evaporation, which is the change of liquid water to a vapor. The warm air then rises up into the atmosphere and becomes involved in condensation.

2.2. Problems

There are two main water-related problems that exist in the world today: pollution and scarcity. Both of these problems exist all throughout the world and both are increasing each year. In addition, both of these problems are affected by, or in some cases caused by, another factor: improper water management. In most ways, these three factors are completely independent and should be discussed separately.

2.2.1. Pollution

The first of the two main water-related problems is pollution. Since the Industrial Revolution, industry has been increasing throughout the world, and with the increase in industry has come a decrease in water quality. This decrease in water quality, or increase in water pollution, has had the greatest effect not on the most industrialized countries, but the countries of the developing world, where waterborne diseases claim the lives of millions each year. Unfortunately, little is being done to remedy the situation.

Groundwater quality is most important in cultures of Third World nations, where quality-monitoring and filtration systems are unavailable. These cultures typically have only one source of water, and thus contamination would affect all of the culture. When a water-source becomes contaminated, the culture has no defense against whatever damage it can cause. The United Nations Water Conference in 1977 found that at least 1/5 of those living in cities and ¾ of those living in rural areas do not have reasonably safe supplies of drinking water (Report of the United Nations Water Conference, 1977). "Each year, 3-4 million people die of waterborne diseases, including more than 2 million children who die of diarrhea" (Cosgrove, 2000).

Groundwater contamination can result from several sources, including biological and chemical contaminants both man-made and natural. Biological contaminants are most common and can include bacteria, viruses, algae, and other microscopic creatures. Biological contaminants are often caused by fecal matter originating in septic tanks and animal feedlots. The nitrates from these sources and others, including fertilizers, landfills, decomposing vegetation, and geological deposits, are said to be the most common cause of groundwater contamination (The Poisoned Well, 1989). Other causes of contamination include leaking solvents from various industries and military bases, pesticides used by farmers, and chlorination used in public swimming pools. Natural contaminants include large deposits of heavy-metals, such as arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. These heavy-metals do damage to living beings by building up in the body over long periods of time, and cause many disorders in the nervous system, liver, kidney, intestine, etc. Most of the causes of groundwater contamination exist in abundance in Third World countries.

Screening for groundwater contamination is a very large and costly process. Most of the methods that have been used in the past, including pH measurement, have recently been discovered to be ineffective or inaccurate. Surprisingly, the most common form of quality control has no means of filtering out pathogens. Instead, the number of pathogens is counted, in relation to the size of the water supply, and at a certain ratio the water source is deemed unsafe.

Industry is one of the top contributors to water pollution. Interestingly, though, the most industrialized countries are not always the most polluted, mainly because most industrialized countries have efficient means of sanitation and laws prohibiting unnecessary pollution. Instead, it is the countries with industry but without proper sanitation that suffer the most from water pollution, including most developing countries. In fact, half of the rivers and lakes in Europe and North America are seriously polluted. As remarkable as that may sound, the situation in developing countries is even worse, without proper waste water management and sanitation (Cosgrove, 2000).

Though North America boasts water quality higher than most places on earth, its ever increasing industry is having a damaging effect. The most industrialized sections of North America, including New England and southeast Canada, are beginning to come to a realization of this fact, as water sources are constantly being closed down from contamination. In addition, these sections are one of the very few places on earth that suffer from acid rain. Acid rain is caused mostly by emissions of sulfide (SO_2) from power stations, and also by nitrogen oxides (NO_x) from road traffic (World in Transition, 1999). In large quantities, acid rain has been known to kill populations of fish in lakes and streams. Acid rain is about as useful to humans as is salt-water, but much more harmful.

Massachusetts, in particular, has had a wave of water pollution in the past decades, which has caused many water sources to be shut down. In July of 1986, 41 communities in Massachusetts were forced to abandon their water supplies because of volatile organic compound (VOC) contamination (Alley, et. al., 1993). Volatile organic compounds were first discovered as contaminants in the 1970's, and since then have appeared in many water sources that were previously thought to be safe.

Since improper sanitation is a direct contributor to water pollution, sanitation is almost always taken into account when describing water problems. Many developing countries suffer from severe lack of sanitation, including some of the same countries that suffer from water scarcity, though the two are not related. The following data represents the percent of the population with access to sanitation: India: 31%, the Democratic Republic of the Congo: 20%, Ethiopia: 15%, Rwanda: 8%, Afghanistan: 12%, Haiti: 28%, USA: 100%, Africa: 60%, Asia: 48%, Globe: 60% (The World's Water: the Biennial Report on Freshwater Resources, 2002-2003). Unlike water scarcity, sanitation is completely controlled by the people (whereas scarcity is mainly controlled by nature), and thus, the people are in the position to improve water quality if they are so inclined. Unfortunately, most of the countries who suffer from improper sanitation also suffer from another factor, the lack of proper management.

2.2.2. Scarcity

The second of the two main water-related problems is scarcity. Water scarcity, like pollution, is most common in developing countries rather than developed countries. Due to the lack of sufficient water supplies , in some cultures people have to live on very little to drink. Each year, these supplies are becoming smaller and smaller, with little relief in sight.

Water scarcity can be caused by aridity, drought, dessication, and water-stress. While the aridity of soil is typically constant, drought can occur anywhere at any time, and little can be done to predict it. Dessication refers to the drying up of a landscape caused by deforestation and overgrazing. Water-stress refers to an increasing number of people relying on a fixed amount of water (Clarke, 1993). While all of the globe suffers from water scarcity, in Africa the situation is worse than anywhere else, where more than 75% of the population lives without drinking water (The World's Water: the Biennial Report on Freshwater Resources, 1998-1999).

Water scarcity can be measured in many ways, but the best way to describe its effect on the public is by the percent of the population with access to safe drinking water. Only after observing these numbers can one truly understand the gravity of the situation: USA: 100%, Kenya: 49%, The Democratic Republic of the Congo: 45%, Ethiopia: 24%, Rwanda: 50%, Afghanistan: 13%, Oman: 39%, and Haiti: 46%. Overall, 62% of the population of Africa, and 82% of the globe, has access to safe drinking water (The World's Water: the Biennial Report on Freshwater Resources, 2002-2003). It is estimated that by the year 2025, 1/3 of the world population will experience severe water scarcity (One Third of Wold's Population, 2.7 Billion...).

North America is one of the few places where 100% of the population has access to safe drinking water and sanitation. It is also one of the places where water withdrawal is highest. North America consumes 400 liters of water per person per day, compared to the 10-20 liters that Sub-Saharan Africa consumes (Cosgrove, 2000). In 1900, the population of the U.S. was 76 million and the water withdrawal was 56 cubic kilometers/year. In 1995, the population of the U.S. was 265 million and the water withdrawal was 554 cubic kilometers/year (The World's Water: the Biennial Report on Freshwater Resources, 2002-2003). Obviously, water withdrawal is increasing much faster than the population. One substantial reason for this is the increase in industry over the past century. Unfortunately, while water use is increasing, water quality is decreasing.

Theoretically, water scarcity is not as serious a problem as many believe. The term 'water scarcity' leads people to believe that water is a rare commodity on Earth, when in fact it is far from it. There is an estimated 1.4 billion km^3 of water on earth; 96.5% of that is located in oceans, 1.77% in ice & glaciers, 1.7% in groundwater, and .03% in lakes and other bodies of freshwater. 41,000 km^3 of water runs to the oceans each year (World in Transition, 1999). While 1.4 billion km^3 seems like a tremendous amount of water, keep in mind that salt-water (which accounts for 96.5% of it) is of little to no use to humans. Virtually all of the water extracted for human use is taken from sources of freshwater such as lakes, groundwater, rivers, and sometimes even glaciers. Many have argued that there does exist enough freshwater on Earth to supply the global human population with more than they require; and so the problem lies not in the existence of freshwater itself, but rather in the difficulty in obtaining water. When an aquifer is tapped for the first time, people usually encounter very little difficulty in extracting the water. However, as time passes, the levels of water in the aquifer typically decrease, and so the wells must be dug deeper. In addition, as water levels decrease, pumps require more energy to extract the same amount of water. For these two reasons, as the water levels decrease the cost of maintaining the water system increases. At some point, the cost of maintaining the system exceeds the value of the water, and thus the system must be scrapped (Rosegrant, et al., 2002). When this happens, it leaves the water that exists below that point completely inaccessible. This is all too common in developing countries.

Water is extracted from the ground for several purposes, including agricultural, industrial, and domestic purposes. Of the water that is used, 69% of it is used for agriculture, 23% for industry, and 8% for domestic purposes. Most of the water used for agriculture is used for irrigation, a process that takes advantage of only about half of the water it uses. Ninety-six percent of all industrial water use occurs in North America and Europe. Most of the water used by industry is used for cooling purposes, which only changes the physical properties of water by raising its temperature a few degrees. This water is exported back to its source to continue its journey to the ocean. Of the water that is used for domestic purposes, most is used for bathing, cleaning, and cooking. Very little of this water is actually used for drinking (World in Transition, 1999).

In addition to water scarcity, Africa also suffers from other water-related problems, including the grueling challenge of actually obtaining the water. In many cultures in Africa, it is the job of the women and children to obtain the water [see picture below]. In order to do this, they must hike a long distance (in some cases, up to 15 miles), pump the water, and carry it back (Developing World Water, 1987). Anyone who has lifted a large bucket of water can understand how difficult this must be. This is a problem not only because of the effort it requires, but because there is a limit to how much water can be obtained in a single trip (depending on the strength of the carrier). Surprisingly, this is a problem than can be easily solved by installing pipes that extend from the water source to the living area. The amount of extra energy required to pump the water this distance would depend on the difference in elevation between the water source and the living area; if the land were horizontal, it would require little to no extra energy at all.

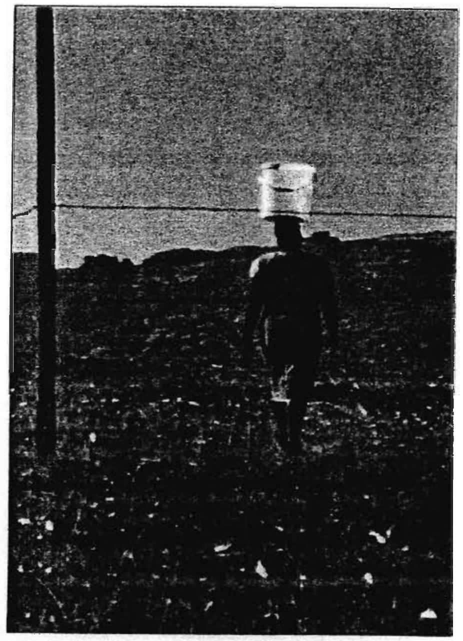


Fig. 2. Carrying water for two km. Lesotho.

Image taken from Developing World Water, 1987.

Irrigation, a wasteful but necessary process used to supply vegetation with water, is used most commonly in arid or semiarid areas. Unfortunately, these are the same areas where water scarcity is most common. Thus, of the water that is available in areas where it is scarce, a large portion of it is wasted, meaning that the water is put into the soil but is never taken up through the roots of a plant. If the efficiency of irrigation were to improve, it would leave a large amount of freshwater available in areas where it is most scarce. The inefficiency of irrigation, like pollution and scarcity, is partially caused by the lack of proper management.

2.2.3. Improper Management

Though it acts in a more indirect than direct way, improper management can be one of the main causes of water-related problems. Improper management refers to the lack of sufficient national or international organization in managing the extraction and use of water. It refers to a system that could potentially act in a more efficient way if it were better organized. Improper management can lead to both of the main water-related problems: pollution and scarcity. In addition, improper management typically prevents a country from fixing whatever water-related problem they may have. Since First World countries typically strive for systems that act in as efficient ways as possible, improper management, like pollution and scarcity, is usually more common in Third World, and sometimes Second World, countries.

Improper management causes water pollution mainly in countries that lack environmental regulations that prohibit pollution. Without these regulations, their country's industries are allowed to continue polluting their environment. Eventually, this pollution reaches the water supply, contaminating drinking water. Often in countries with improper management, the country lacks the ability to test the water, and so the public is often unaware that their water is contaminated.

Improper management affects water scarcity in several ways, the first of which is the extraction of water. The improper management of water extraction can be measured in a fairly accurate way: unaccounted-for-water. Unaccounted for water (UFW) is a measure of the amount of water taken from a water source that is lost before it is put to use. The higher the level of UFW, the less efficient the water system is, and the more water it wastes. In a well-managed system, UFW levels would be at about 10-15%. In many developing countries, UFW levels have reached and even exceeded 50% (Rosegrant, et al., 2002). This means that half of the water pumped from its source will be lost on the way to its destination. The following data represents UFW levels for various areas: Africa(large city average): 39%, Asia(large city average): 35-42%, Algiers, Algeria: 51%, Canada: 15%, Damascus, Syria: 64%, Gaza: 31%, Vietnam: 50%, Teheran, Iran: 35%, Sana'a, Yemen: 50%, Nairobi, Kenya: 50%, Mexico City: 32%, Mandalay, Myanmar: 60%, United States: 12% (The World's Water: the Biennial Report on Freshwater Resources, 2002-2003). Fortunately, though, a higher level of UFW means that there is more room for improvement and, more importantly, that more water is available.

Another way in which improper management affects water scarcity is improper management of irrigation. As stated before, irrigation is a wasteful but necessary process of supplying vegetation with water; this process only takes advantage of, on average, about half of the water it uses. Many believe that there should exist strict guidelines outlining when irrigation should and should not be used. Cited in Irrigation Development in Africa: Lessons of Experience, Steinberg gives the following times when irrigation should not be used: "when there is an unresolved presence of irrigation failure in the past", "when economic policies or institutions are weak", "where there are poor agricultural pricing policies, ineffective marketing facilities, high transport costs, or the unavailability of required agricultural materials", "if the institutional capacity to manage irrigation has not been demonstrated or if overall management is weak", etc (Moris, et al., 1990, pg. 33). In many developing countries, including large parts of Africa, irrigation is being used where one or more of these previous conditions is true. In general, since it wastes a significant amount of water, irrigation should not be used when water is very scarce. Unfortunately, it is where water is scarce that irrigation is most important.

A third way in which improper management affects water scarcity pertains to how water systems are built and managed. When building water systems for a developing country, engineers often focus only on the engineering aspect without taking into account the people who will use the system. The engineers often try to develop a universal system rather than a personalized one. When this happens, the people often fail to understand the system and its significance. When a system is developed specifically for the people who are going to use it, it is more likely to be accepted and used, for the same reason that a custom-built appliance is more likely to be put to use than one that is factory-built. For this reason, it is important to use a "bottom-up" [explain this!] approach when designing a water system for a developing country, and to design a system specifically for the people who will use it (<u>The World's Water: the Biennial Report on Freshwater Resources</u>, 2002-2003). In most cases, this would mean conversing with the people long before any plans are drawn up.

As stated, there are two main water-related problems that exist in the world today: pollution and scarcity. Both these problems are affected by a third factor, improper management. These three factors exist in abundance in the Third World. With each passing year, the global water situation gets worse and worse. Some in the First World believe that this is a situation specific to the Third World; it is certainly not. Many believe that it is merely a matter of time before all of the world's human population suffers the same way that the people of the Third World suffer today. If the people of the

First World wish to prevent this from happening to themselves and their ancestors, it is imperative that we look at the Third World as our future.

2.3. Hydraulics

Hydraulics is the study of the movement of fluids; however this section deals only with the movement of groundwater. Knowledge of hydraulics is a necessary part of the well design process, because it is the underlying framework of every well. Without an understanding of the behavior of water, one cannot hope to maximize the yield or efficiency of a well. The following sections briefly discuss some of the major concepts of groundwater hydraulics.

2.3.1. Porosity

Porosity (n) is defined as the index of how much groundwater can be stored in a saturated medium. It is the ratio of the volume of pore space to the volume of bulk solid.

$$n = \frac{V_p}{V_g}$$

Example 1 – What volume of solid material is present in 1 cubic foot of sandstone, if the porosity of the sandstone is 0.20? (Bennett, 1976, p. 3)

- Identify known variables: $n = 0.20$; $V_g = 1\ \text{ft}^3$
- Solve equation through algebra:

$$0.20 = \frac{V_p}{1\ \text{ft}^3}$$
$$V_p = 0.20\ \text{ft}^3$$

- V_p is the volume of pore space. To find the volume of solid material, subtract from the total volume:

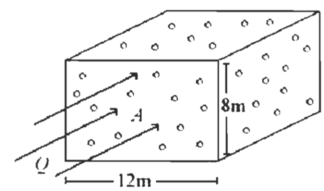
$$V_s = 1\ \text{ft}^3 - 0.20\ \text{ft}^3$$
$$V_s = 0.80\ \text{ft}^3$$

2.3.2. Discharge

Discharge (Q) is "the quantity of flow per unit time, such as gallons per minute (gpm) or cubic meters per second (m^3/s) (Driscoll, 1986, p. 74)." Specific discharge, or specific flux, (q) is a ratio of the discharge through a segment of porous material and the gross cross-sectional area of the segment.

$$q = \frac{Q}{A}$$

Example 2 – In the block of saturated porous material in the figure at right, a fluid discharge is crossing the area, A, at right angles. A represents the gross area of the block face, including both solid particles and fluid-filled pore space. If the value of the discharge is 25 m^3/s, what is the specific flux? (Bennett, 1976, p. 4)



- Identify known variables: $Q = 25\ m^3/s$
- Find A by using the formula for area

$$A = l * w$$
$$A = 12m * 8\ m$$
$$A = 96\ m^2$$

- Solve equation

$$q = \frac{25\ m^3/s}{96\ m^2}$$
$$q = 0.260\ m/s$$

2.3.3. Hydraulic Head

Elevation head (z) at a point is the distance of the point above an arbitrary datum. The pressure head (h_p) at a point is the distance of the point to the top of a static column of water that is supported above the point. The total head (h) at a point is the sum of the elevation head and the pressure head.

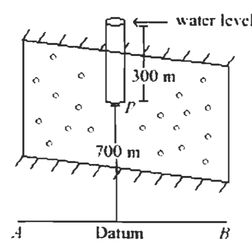
$$h = z + h_p$$

Head loss (Δh) is defined as the difference in head between two points.

$$\Delta h = h_1 - h_2$$

Example 3 – The figure below represents an enclosed porous filter bed. The plane *AB* is taken as the datum, and a pipe is inserted to the point *p*.

What is the head at point *p*? (p. 7)



- Identify known variables: $z = 700$ m; $h_p = 300$ m
- Solve equation

$$h = 700 \text{ m} + 300 \text{ m}$$
$$h = 1000 \text{ m}$$

Example 4 – In the figure above, if a point p_2 is 600 m above the plane *AB* and a 200 m pipe is inserted to the point p_2, what is the head loss between points *p* and p_2?

- Identify known variables: $h_1 = 1000$ m; $z_2 = 600$ m; $h_{p2} = 200$ m
- Solve for the head at point p_2

$$h_2 = 600 \text{ m} + 200 \text{ m}$$
$$h_2 = 800 \text{ m}$$

- Solve equation

$$\Delta h = 1000 \text{ m} - 800 \text{ m}$$
$$\Delta h = 200 \text{ m}$$

2.3.4. Hydraulic Conductivity

Hydraulic conductivity (*K*) is the capacity of a porous medium to transmit water. It is a vector measurement that incorporates both the properties of the fluid and the medium. Intrinsic permeability (*k*) is a scalar measurement that is closely related to the hydraulic conductivity. It also measures the capacity of a porous medium to transmit water, but is not dependant on the properties of the fluid.

$$k = K \frac{\mu}{\rho g}$$

where μ is the dynamic viscosity of the fluid, or its tendency to resist flow, ρ is the fluid density, and *g* is the gravitational constant (9.8 m/s^2). (p. 71)

Example 5 – Given that the fluid density of water is 1000 kg/m^3, its dynamic viscosity is 500 kg/(m s), and the intrinsic permeability of the medium is 10 m^2, find the hydraulic conductivity.

- Identify known variables: ρ = 1000 kg/m^3; μ = 500 kg/(m s); g = 9.8 m/s^2; k = 10 m^2
- Solve equation

$$10 \text{ m}^2 = K \frac{500 \text{ kg/(m s)}}{1000 \text{ kg/m}^3 * 9.8 \text{ m/s}^2}$$

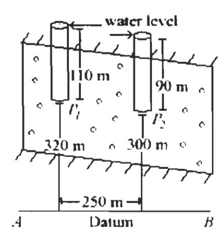
$$K = 196 \text{ m/s}$$

2.3.5. Hydraulic Gradient

The hydraulic gradient (I) is the slope of the water table. It is calculated by dividing the head loss between two points by the distance between the two points. (p. 73)

$$I = \frac{\Delta h}{l}$$

Example 6 - The figure at right represents an enclosed porous filter bed. The plane AB is taken as the datum, and pipes are inserted to the points p_1 and p_2. What is the hydraulic gradient?



- Identify known variables: z_1 = 320 m; h_{p1} = 110 m; z_2 = 300 m; h_{p2} = 90 m; l = 250 m
- Solve for the head at point p_1

$$h_1 = 320 \text{ m} + 110 \text{ m}$$

$$h_1 = 430 \text{ m}$$

- Solve for the head at point p_2

$$h_2 = 300 \text{ m} + 90 \text{ m}$$

$$h_2 = 390 \text{ m}$$

- Solve equation

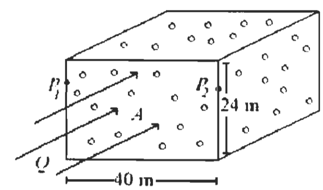
$$I = \frac{430 \text{ m} - 390 \text{ m}}{250 \text{ m}}$$

$$I = 0.160$$

2.3.6. Darcy's Law

In 1856, French engineer Henry Darcy discovered that "the flow rate through a porous medium is directly proportional to the head loss and inversely proportional to the length of the flow path" (Design and Construction of Water Wells, 1988, p. 19). This relationship is called Darcy's law and is expressed by the following equation:

$$Q = KAI$$



Example 7 – In the figure at right, the discharge is 10 m^3/s and the head loss between points p_1 and p_2 is 15m. Find the hydraulic conductivity.

- Identify known variables: Q = 10 m^3/s; Δh = 15 m; l = 40 m; w = 24 m
- Solve for the area

$$A = 40 \text{ m} * 24 \text{ m}$$
$$A = 960 \text{ m}^2$$

- Solve for the hydraulic gradient

$$I = \frac{15 \text{ m}}{40 \text{ m}}$$
$$I = 0.375$$

- Solve equation

$$10 \text{ m}^3/\text{s} = K * 960 \text{ m}^2 * 0.375$$
$$K = 0.028 \text{ m/s}$$

2.3.7. Transmissivity

As stated earlier, hydraulic conductivity is the capacity of a material to transmit water. This applies only to a unit volume of the material. Transmissivity (T) is the ability of the entire aquifer to transmit water. It is measured by multiplying the hydraulic conductivity by the thickness of the aquifer.

$$T = Kb$$

Example 8 – If the hydraulic conductivity of a 700 m deep aquifer is 0.3 m/s, what is the Transmissivity of the aquifer?

- Identify known variables: K = 0.3 m/s; b = 700 m
- Solve equation

$$T = 0.3\ \text{m/s} * 700\ \text{m}$$
$$T = 210\ \text{m}^2/\text{s}$$

2.3.8. Cone of Depression

In an inactive well, the water level inside is called the static water level. The water level in a well that is being pumped at a constant rate is the pumping water level. When a well is pumped the head inside the well decreases, causing the water in the aquifer to flow into the well from all directions. This flow pattern is called converging flow. In an aquifer of uniform texture, the pattern takes the shape of an inverted cone, called the cone of depression (Figure 2.3.1). The apex of the cone is at the pumping water level and its base is at the static water level. The land surface distance from the center of the well to the outer edge of the cone of depression is called the radius of influence.(p. 22)

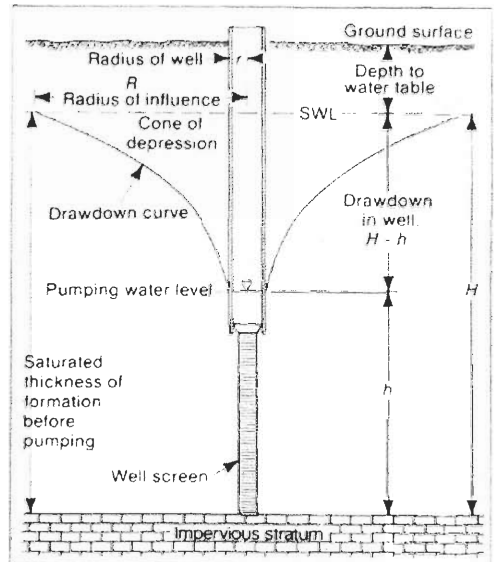


Figure 2.3.1. Cone of Depression (Driscoll, 213)

When the pumping of a well begins, the cone of depression is small. As pumping continues, the cone grows, and will continue to grow until a state of equilibrium is reached. There are four ways a well can reach equilibrium:

1. Natural discharge from the aquifer equals the pumping rate of the well
2. A body of surface water is intercepted by the cone of depression from which water enters the aquifer at an equivalent pumping rate
3. Recharge from precipitation and other vertical infiltration within the radius of influence equals the pumping rate
4. Recharge from adjacent aquifers equals the pumping rate. (p. 24)

Some wells will reach equilibrium within hours of pumping onset, while some wells never reach a state of equilibrium even after years of use.

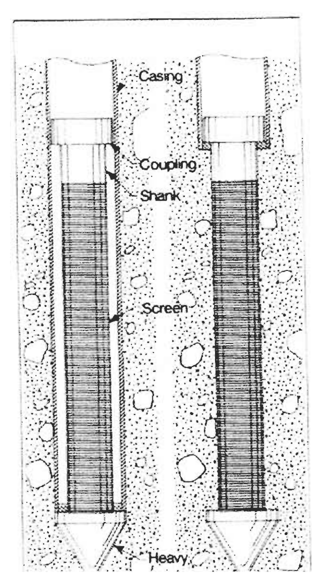
3. Wells

3.1. Types of Wells

When discerning the type of a well, there are several ways with which to categorize it. The two most frequently discussed categories are construction and design. In terms of construction, there exist three main types of water wells: dug, driven, and drilled. There are also three main design types: gravel envelope, naturally developed, and water bearing rock.

3.1.1. Construction

Dug wells are excavated manually with a shovel until the hole reaches below the water table. This large diameter well is then lined with stone, brick, or similar material to prevent collapse and covered with a lid made of wood or concrete. Because of their crude construction that relies solely on manpower, dug wells are extremely cheap and easy to make. The drawbacks of these wells, however, are the reason that they are being used less and less throughout the world. Dug wells can only draw from shallow aquifers, they are exposed to more contaminants because they lack a continuous casing, and oftentimes in the dry season, the water level will drop to below the well's bottom, rendering it useless.



Driven wells are also used exclusively with shallow aquifers; they are generally no more than 30 feet deep. To create a driven well, a pointed well screen is attached to a steel pipe having a diameter of about 2 inches (see Figure

3.1.1). The pipe is then driven into the ground by hand or by machine. "Hand driving is best done with a weighted pipe, similar to the type used for driving steel fence posts" (Driscoll, 1986, p. 314). Driven wells are cheap and economical, but like dug wells, the water they tap has a greater potential for contamination.

Drilled wells are by far the most common type of well in technologically advanced areas. They can reach depths of up to 5000 feet, although it is a rare case in which the well needs to be that deep. Drilled wells provide water with less contamination than driven or dug wells because they use a solid casing which is surrounded by grouting material to prevent leaks. They also require heavy machinery and so are quite expensive to construct, making them an unreasonable option for many poorer countries.

There are many drilling methods that can be used, most commonly the cable tool method and direct rotary drilling. Cable tool drilling was the earliest drilling method and has been in use for over 4,000 years. The machines operate by continually lifting and dropping a heavy string of drilling tools (drill bit, drill stem, drilling jars, swivel socket, and cable) into the borehole (see Figure 3.1.2). Direct rotary drilling (see Figure 3.1.3) was developed to produce deeper wells. The borehole is made by rotating a bit, and the cuttings are removed by

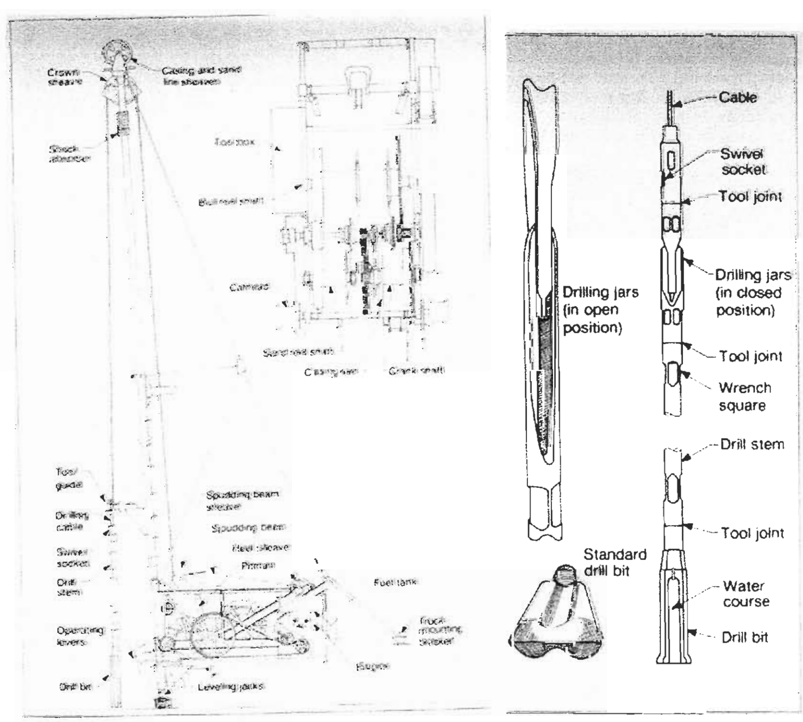


Figure 3.1.2. a) Cable tool drilling machine; b)string of drilling tools (Driscoll, 270,271)

continuous circulation of a drilling fluid. (p. 278)

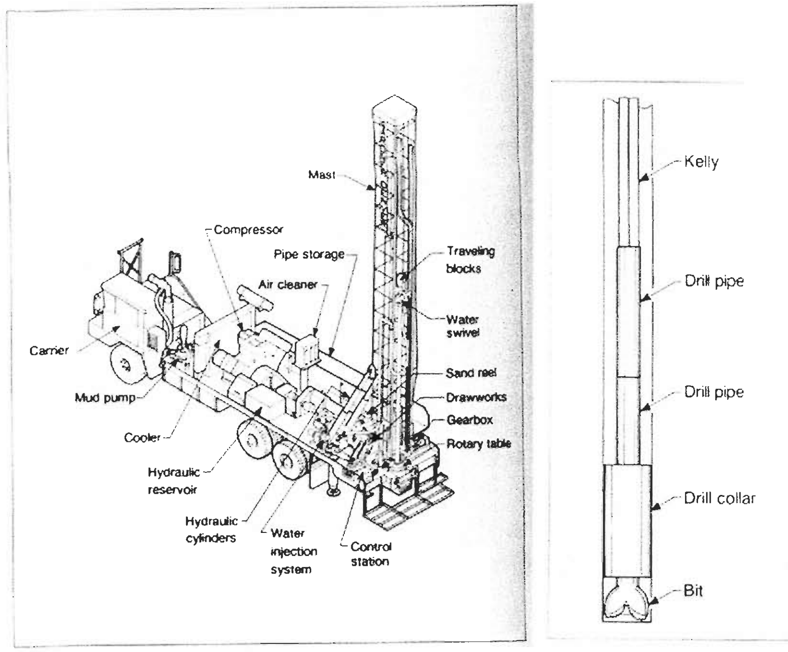
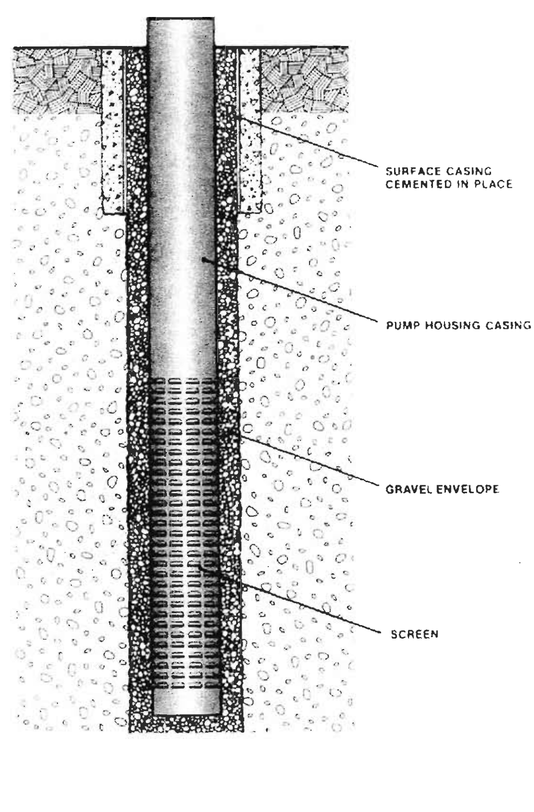


Figure 3.1.3. a) Direct rotary drilling machine; b) drill bit (Driscoll, 278,284)

3.1.2. Design

Gravel envelope wells (see Figure 3.1.4.) are always drilled, usually by direct rotary. They consist of an oversized borehole containing the well casing and screen and a formation stabilizer or filter pack. A formation stabilizer used to keep the borehole open and prevent the well from collapse or cave-in. A filter pack is created by replacing some of the formation materials with special materials with good porosity. This creates a space between the screen and the formation material which increases the effective



diameter of the well. (p. 439) Gravel envelope wells are a good choice when the aquifer consists of fine sands that must be filtered.

Naturally developed wells have a casing that penetrates the complete depth of the aquifer. Most often parts of the casing are perforated in place to form a screen, although in some cases separate material is used to construct the screen. This type of well is generally chosen when the aquifer is well defined and made up of well graded sands and coarser materials. Naturally developed wells are very often the design choice for high capacity wells, because they offer long and trouble free operation. (The Engineers Manual for Water Well Design, 1985, pp. 16, 26)

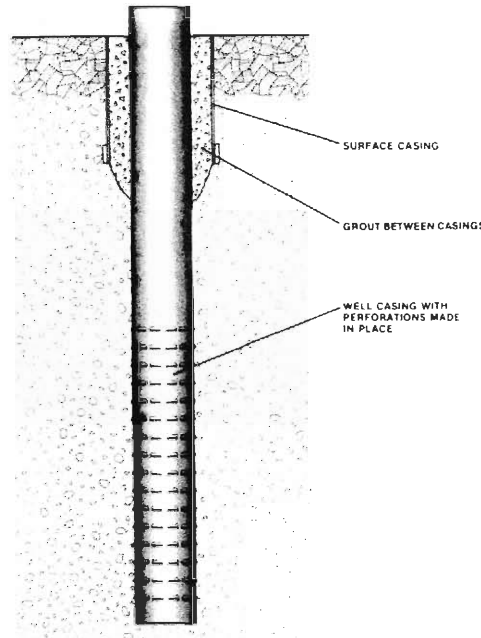


Figure 3.1.5. Naturally developed well (Engineers Manual for Water Well Design, 17)

Wells in water bearing rock, such as basalt or limestone, have casing that reaches down to the top of the producing zone of the rock and an open hole drilled below. If the rock has fine sand or silt in the water, a screen is put in place of the open hole. In either case, the casing is cemented to its entire depth to prevent the entrance of surface water. (pp. 20, 22, 26)

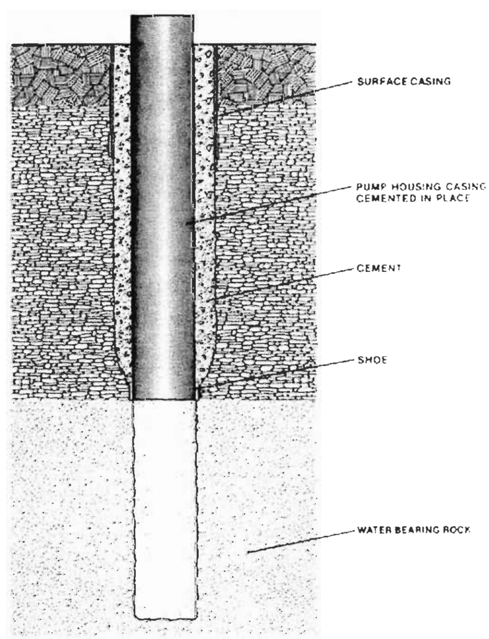


Figure 3.1.6. Well in water bearing rock (Engineers Manual for Water Well Design, 21)

3.2. Functions

The water wells discussed in this paper are all production wells, or wells that provide a water supply. Industrial, municipal, and irrigation wells are considered high-capacity, while farm and domestic wells are low-capacity. Although water supplying wells are the most well known type of well, they are certainly not the only kind.

Groundwater monitoring wells are used to measure groundwater levels and to take samples of the water to test for contamination. This is often where the designer of a new well acquires needed information. Dewatering wells are commonly used in construction sites to lower the groundwater level to a specified depth and maintain that depth until all below ground construction is complete. Pressure relief wells are used to relieve hydrostatic pressure from a dam or levee. Injection wells have an assortment of uses, including groundwater control, artificial recharge of groundwater systems, waste disposal, and the mining of certain minerals. Wells can also serve as heat pumps that extract heat energy from water and make it available for cooling and heating.

3.3. Design

"A successful well is the culmination of a series of evaluations and decisions, ranging from preliminary consideration of area aquifer properties to operating procedures after the well is in service. The synthesis of this process is the well design. (p. 1)"

3.3.1. Site Evaluation

Before any design decisions can be made, the use and expected life of the well must be determined, as well as the amount of water it should yield. The usage of the well reflects the design. For instance, a well supplying city drinking water is constructed using much higher standards than a temporary well at a construction site. The latter need not worry about water quality or a long lifespan. (Design and Construction of Water Wells, 1988, p. 75) Without knowing the use of the well, the rest of the design process is futile.

The environment surrounding a well plays an extremely large part in its design and construction. One of the first things to consider is the aquifer that will be tapped. Some of the key information that needs to be collected is the size and depth of the aquifer, the material of which it is composed, and the quality of the water contained therein. Often this data can be obtained through nearby wells that tap the same aquifer, but in some cases when there are no records readily available, a test hole is drilled nearby and new data is collected.

The area around a chosen well site also plays a role in the design process. The well itself represents the minimum amount of space needed. The actual amount of space should be determined using a method such as a cost/benefit ratio. For example, a smaller well site will certainly cost less to maintain, but there may not be enough space to fit the optimal drilling equipment. Expanding the size of the site will raise the cost, but may also allow for equipment that can construct the well cheaper and more efficiently. In addition to size, the locale of the well site is also an issue. Trees and hills, among other things, can make a site inaccessible to equipment, so the design of wells in obstructed areas would surely be different than the design of wells in open land.

3.3.2. Casing

The casing of a well is the part that connects the aquifer with the surface. It protects against water contamination, allows access to the aquifer, and structurally supports the sides of the borehole for the lifespan of the well. There are two important design decisions that must be made regarding casing: diameter and material.

The diameter should be chosen to satisfy three requirements. First, it should be capable of obtaining water from the aquifer as efficiently as possible without being oversized. Next, it should support the yield of the well without exceeding an uphole velocity of 1.5 m/sec. And last, the casing must be large enough to accommodate the desired pump with adequate space for any tools needed in the installation process. "It is recommended that the casing diameter be two pipe sizes larger than the nominal [inside] diameter of the pump. In all cases, however, the casing must be at least one nominal size larger than the pump bowls." (Driscoll, 1986, p. 416)

Once the diameter has been determined, the next step is to select the material of the casing. The most common material used is carbon steel because it is inexpensive and resists atmospheric corrosion. When conditions are mildly corrosive, it has been shown that adding a small percentage of copper to the carbon steel extends the life of the casing and almost doubles its corrosion resistance. Another material used in mildly corrosive environments is high tensile, low alloy steel, which generally has a corrosion resistance at least four times better than carbon steel. In very corrosive conditions stainless steel can be used, and although the cost is much higher than carbon steel initially, it pays off over time because the well will last longer.

Sometimes the corrosion is so extreme that even stainless steel pipes fail within a short amount of time. In situations like these, thermoplastics have recently become a widely used casing material. Some of the most common types of plastic casing are acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and styrene rubber (SR). Because these plastic pipes are more flexible than their steel counterparts, the risk of collapse is increased. For this reason it is not recommended to use plastic casing for wells deeper than 91.5 m, although it is done nevertheless.

3.3.3. Intake

The intake, also called a well screen, is a filtering device that "permits water to enter the well from the saturated aquifer, prevents sediment from entering the well, and serves structurally to support the unconsolidated aquifer material." (p. 395) Like the well casing, design decisions regarding measurements and materials must be made, but with the addition of choosing the type of well screen.

The continuous-slot screen is the most commonly used well screen. It is made by winding cold-rolled, triangular-shaped wire around a circular array of longitudinal rods. The slot size is generally between 0.15 and 6.4 mm and is v-shaped to prevent clogging. A second type of screen is the pipe-base screen. It is constructed by first punching slots into a plastic or metal pipe that is being used as the casing. Then a trapezoid-shaped wire is wound around the pipe. Unless the materials used for the wire and the casing are the same, pipe-base screens generally have short life spans, making them a less than popular choice. Another option is louvered and bridge-slot screens, which have openings arranged in rows that are oriented either parallel or perpendicular to the screen axis.

These screens can only be used in filter-packed wells. (p. 402) The simplest type of intake is one in which slots are cut directly into the casing by saw, welding torch, or machine. These are generally used for test wells or low-yield domestic wells, because they are inexpensive and easy to make, but not as efficient as other more complex intakes. (Design and Construction of Water Wells, 1988, p. 87)

Once the type of screen has been chosen, the next step is to find appropriate measurements for the screen length, diameter and slot openings. The length of the screen is largely determined by the aquifer and plays a large role in the efficiency of the well. "Given an amount of water that will be withdrawn from an aquifer, an intake that penetrates the full thickness of the aquifer will yield that water more easily than one that penetrates only 50% of the aquifer's thickness. More head is needed to force the same quantity of water through a smaller area as well as creating a longer path line for some ground water to move along before it enters the well. (p. 100)" The diameter and slot openings are easier to determine, because they are derived from already known details of the well design. The diameter should provide enough open area such that the entrance velocity of the water is no more than the design standard of 0.03m/s. In naturally developed wells the slot opening size should allow about 60% of the material to pass through. (Driscoll, 1986, p. 435)

Finally, the selection of material for the well screen is based on three factors: water quality, potential presence of iron bacteria, and strength requirements of the screen. Water quality refers to the corrosiveness of the water, and the screen material is selected in the same way, and from the same options, that the casing material is chosen. Iron bacteria in water is not harmful to humans, but can cause clogging in the screen which will reduce yield over time. It is recommended to use corrosion-resistant materials when iron bacteria are present. Strength of the screen is not a main factor in choosing the material. Generally only large diameter wells at depths greater than 91.5m need to take strength into consideration.

3.4. Pumps

Pumps are used in many situations to add hydraulic energy to certain volumes of fluid. Pumps in water wells are used in three distinct phases. First, development pumping is done during the construction of the well as a means of removing the discharge from the borehole. Second, test pumping is done to confirm the maximum safe pumping rate and the permanent pumping rate of the well. Lastly, when the well is completed, the pump is what makes it functional.

Shallow wells (approx. 7.5m or less) usually have their pump mounted at ground level and remove the water by suction lift. Any well that is too deep to use suction lift has its pump installed within the casing below the pumping level of the water. These rules apply to each of the three pump designs: variable displacement, positive displacement, and free surface.

3.4.1. Variable Displacement Pumps

Variable displacement pumps are generally used for domestic and high-capacity wells. Their defining characteristic is "the inverse relationship between the rate at which they deliver water and the head against which pumping takes place (Driscoll, 1986, p. 581)." As the head increases, the rate of pumping decreases.

The centrifugal pump is the most common variable displacement pump because it can efficiently deliver large quantities of water against both high and low head. It operates using centrifugal force, which is the force that pushes an object away from the center of a rotating circle. There are four types of centrifugal pump: turbine, volute, mixed-flow, and axial-flow.

The turbine has an impeller that is surrounded by diffuser vanes. These vanes are gradually enlarging passages that reduce the velocity of the water and thereby increase the pressure. Turbine pumps are the standard for water well use. The impeller on a volute pump sits in a spiral-shaped case that also reduces the velocity of the water. Mixed-flow pumps use both the centrifugal force of an impeller and the lifting action of a propeller. Axial flow pumps use only the lift of a propeller to move water. Mixed-flow and axial-flow pumps can only be used in wells with very low head. (pp. 587-588)

A second type of variable displacement pump is the jet pump, which is a combination between a centrifugal pump and a nozzle-venturi arrangement. They are inefficient compared to regular centrifugal pumps, but they are often used in domestic wells because they are easily adaptable to small wells and are relatively inexpensive. (pp. 602-604)

3.4.2. Positive Displacement Pumps

Positive displacement pumps discharge the same amount of water regardless of the head, but require more input power as the head increases. They essentially force water to move in one direction, and prevent flow in the opposite direction. This type of pump is used for groundwater monitoring wells, hand pump equipped wells, and other low-capacity wells. Some examples of positive displacement pumps are rotary pumps, piston pumps, and diaphragm pumps. (pp. 604-606)

3.4.3. Free Surface Pumps

Free surface pumps move water by physically lifting it in moving containers. This type of pump is generally only employed in a low-yield well. A simple example of a free surface pump is a bucket on a rope that is thrown down into a well and then hauled back up full of water. Some more complex examples include an Archimedean screw, a scoop wheel, and a bucket pump.

3.5. Wells in the Developing World

3.5.1. Well Design and Construction

Countries in the developing world often lack both the technology and funds required to construct the types of wells that have been mentioned in this paper. As a result, their wells are generally much simpler and unfortunately of lesser quality. <blah>

The use of local materials for the well casing and screen is not uncommon. For example, some wells in Egypt use hollowed out date tree trunks as casing, and in India many wells are cased with bamboo. While these crude structures are inexpensive and serve their purpose of supplying water, they are certainly not very efficient or safe. Bamboo wells only last up to three years, and the borehole can not be reused with new casing. In addition, neither bamboo nor tree trunks prevent against contamination of the water. There are plenty of local materials, however, that make a safe and efficient well. These include wrought iron piping, tubing rolled from sheet metal, glass reinforced plastic, concrete tile, and clay tile, as well as some materials common in the first world. (Koegel, 1977)

A lack of education is also a major cause of inefficiency. In many parts of the developing world, secondary education is unheard of, and primary education is available only to the more fortunate. Without the proper mathematical and engineering background, designing an efficient and safe well is nearly impossible. The same is true for maintaining a well that is currently in use.

In recent years, several organizations have developed programs that seek to combat the global water problem by providing safe and efficient wells to communities in the developing world. Some of these programs are conducted with speed in mind; the faster we build, the more we can build. This type of approach tends to lead to negative results. Occasionally the construction of a new well will bring about a local outbreak of a parasitic disease, specifically malaria, filariasis, onchocerciasis, and schistosomiasis. (Hunter, et al, 1993) More commonly though, the villagers simply do not understand the well system and therefore cannot properly maintain it.

Other programs choose to include the community in the well building process. Instead of simply building the well and moving on, they build the well with the residents of the community, using techniques from both the village and the first world. They also teach them the importance of the well, and how it works. Before leaving the site, they often designate a member of the community to maintain the well. When the community is involved in the making of their well, they have a better understanding and appreciation of it, and the results are generally better.

3.5.2. Handpumps

A vast majority of water wells in the developing world use handpumps. They are inexpensive, low maintenance, and often so simplistic that young children can use them with ease. There are a plethora of different types of handpumps, some being specific to one country, others used worldwide. While it is impractical to discuss the characteristics of every handpump, an extensive gallery of photos can be found in Appendix 5, along with other types of pumps.

There are, however, several handpumps deserving mention. The India Mark II pump, for example, has been named the best handpump in the world by the United Nations Development Programme (UNDP). This is based on its ease of use/installation, efficiency, and acceptance in the community, among other things. (SK Industries) It produces water through the up and down movement of a plunger, and is the standard handpump for water wells in India. The Afridev pump is quite similar both visually and mechanically. It is widely used in both Africa and Asia. Another popular handpump is the Volanta, which originated in the Netherlands but is widely used in Africa. It has a large wheel that is spun to produce water, and is designed to last for long periods in harsh conditions. The Tara pump is small and uses suction lift to produce water. It is operated by pumping up and down, much like a bicycle pump. The Rower pump sits on an incline, and is operated by a push and pull similar to a rowing machine. Lastly, the Vergnet pump is operated with a foot pedal rather than by hand. Of course not all wells in the developing world are equipped with handpumps. Some use free surface pumps, while others have pumps that are powered by solar or wind energy.

3.5.3. The Well Site

Wells in the developing world serve another purpose that first world wells do not. Often the well is situated near the center of the village, and serves as a hub or meeting place for the community. Each day the women and girls fetch water from the well, and they spend this time gossiping and socializing. The community well can perhaps be seen as similar to an office break room where coworkers chat over coffee.

Sometimes the village is not lucky enough to have its own well. In cases such as these, the women and girls have to walk several miles to reach the nearest well, and then carry the water back in large pots on their heads. This greatly decreases the social aspect of the well, because it is no longer a convenient meeting place; no one will make the trip unless they need the water. If the well is situated near a road, it will sometimes be equipped with a trough to provide water for any animals that may be accompanying a traveler. The trough is generally made of concrete and surrounds the pump area, which is slightly raised. Any water that is not collected drains into the trough.

4. Filtration Systems

Filtration is "the removal from water of objectionable polluting material that can not be taken out by simple subsidence, or by chemical treatment. (Fuertes, 1901, p. 3)" These contaminants range from metals that affect water's color and taste, to microorganisms that cause fatal disease. There are various different methods of treating water, each designed to remove certain pollutants. The most common methods are discussed in this section.

4.1. Distillation

Distillation is the process of removing minerals, metals, and other sediment by boiling the water, collecting the steam, and then condensing it. Any element that will not boil or evaporate remains in the distiller and must be removed. The distiller requires constant electricity, and it takes about two hours to produce a single gallon of water. For these reasons, this method is impractical for large-scale use, but can be economical for treating home drinking water.

4.2. Sediment Filters

Sediment Filters are designed to catch dirt, sand, mineral, metal, and other small particles. They are very economical, because they require no outside energy and produce water quickly. There are two types of sediment filters: fiber and ceramic. Neither type will remove contaminants dissolved in water, such as lead, mercury, and organic compounds.

Fiber Filters use a material such as rayon that is spun into a mesh with small pores. The sediment is removed as the water pressure forces water through the tightly wrapped fibers. The size and mesh of these filters varies from fine to coarse. The finer the mesh, the more particles are trapped and the more often it needs changing.

Ceramic Filters work much the same as fiber filters, substituting ceramic for mesh. If the pores are small enough, they can filter out asbestos fibers, cysts, and some bacteria. They can also be used in combination with an activated carbon filter to provide a more complete removal of contaminants. (Drinking Water Resources, 2003)

4.3. Activated Carbon Filters

"Activated carbon is particles of carbon that have been treated to increase their surface area and increase their ability to adsorb a wide range of contaminants. (ibid)" Adsorption occurs when a dissolved substance becomes attached to the surface of the carbon. Like a sediment filter, this is another method of filtration that does not require outside energy. It is important to note that hot water should never be used in an activated carbon filter. Not only will it damage the filter, but it may release trapped contaminants into the water flow, potentially making it more contaminated than the water flowing in.

In a granular activated carbon filter (GAC), water flows through a bed of loose activated carbon granules that trap certain particles and remove some chlorine and organic contaminants. There are three drawbacks to this type of filter. First, the water can carve a channel. Any water flowing through that channel has no contact with the filter. Second, pockets of contaminated water can form. Changes in flow rate and water pressure sometimes cause these pockets to collapse, and the contaminated water is dumped through the filter. Last, the effective pore size of the filter is large, so small particles like bacteria or giardia cysts can not be removed. (ibid)

Another type of activated carbon filter is the solid block activated carbon filter (SBAC). In this method, the carbon has been "specially treated, compressed, and bonded to form a uniform matrix. (ibid)" This greatly reduces the effective pore size of the filter, eliminating the problems that occur with the GAC. The larger surface area and longer contact time allows for a more complete contaminant removal. (ibid)

4.4. Deionization

Deionization, sometimes referred to as ion exchange, is used to demineralize water. In this method, water passes through deionization resins, which are small, porous beads. Each pore is known as an exchange site. As the water flows through, cations such as sodium, calcium, or magnesium are exchanged for a hydrogen ion (H+). At the same time, anions, chloride and sulfate for example, are exchanged for a hydroxyl ion (OH-). The hydrogen and hydroxyl ions then react to form water. Once every exchange site on the resin has been used, it must be replaced. (Driscoll, 1986, p.829)

4.5. Reverse Osmosis

Osmosis is the process of water molecules moving through semi-permeable membranes. In reverse osmosis, the water molecules are forced to move from a concentrated solution through a semi-permeable membrane. This method of filtering removes salt and most inorganic material. Microscopic parasites are usually removed, but the slightest defect in the membrane, and they may be allowed to pass through.

While reverse osmosis is very thorough, it does have some drawbacks. First, it comes as a large unit with several parts: a sediment pre-filter, reverse osmosis membrane, storage tank, and activated carbon post-filter. It is quite expensive, with prices ranging from $700-$2000. It also wastes a great deal of water. For every gallon of pure water produced, there are 2-4 gallons of waste water that must be discarded. Therefore, this type of water treatment should only be used when the situation necessitates it. (Drinking Water Resources, 2003)

4.6. Ultra Violet Light

In an Ultra Violet (UV) Light system, water flows through a clear tube where it is exposed to UV light that kills bacteria and deactivates viruses. This method is not effective against any non-living contaminants, so it is most often used as the final purification stage in some filtration systems. In addition it is very expensive and potentially harmful to humans.

5. Education

The study of environmental education is one that is rarely taught beyond a cursory glance, if even at all, in modern classrooms. Those classrooms where it is taught rarely articulate its significance. This particular study is one that has not evolved over time, as other studies have, but has instead degraded to the point where it has lost all meaning. What once was taught to children as a necessity for survival is today ignored as if it had no relevance in reality.

Environmental education is a study that has been around as long as humans "have been interacting with the world around them and teaching their children to do the same" (Meadows, 1989). Unlike other educational studies, environmental education is not held as significant today as it was in earlier times. The main reason for this is that it is not necessary for survival, as it was long ago; or at least, it is not *perceived* to be necessary for survival. Ironically, environmental education has never been as relevant as it is today.

In earlier times, environmental education was taught by parents to children at a young age as a fundamental necessity for survival. Humans then considered themselves to be a part of nature like any other organism, and therefore held themselves responsible for the quality of the environment. This was a time when humans lived in nature, and would no sooner harm it than they would harm their own shelter (Sytnik, 1985). This was a time when lakes were safe to drink, air was safe to breath, plants were a source of nourishment, and animals existed above and below humans on the food chain. This was a time when the laws of Darwin and Karma applied to humans. Unfortunately, this time is long past.

Today, humans are not part of, and do not live in, nature. They live in houses and buildings built by other humans whom they have never met. Inside they are protected from the outside-pollution with double-paned windows and air-duct filters. Safe drinking water is a fading dream; only a fool would drink water from the local lake. The level of smog over urban areas is reported with the weather, as if it were a natural phenomenon. Slaughterhouses and rifles have taken humans out of the food chain. This is a time when humans are thriving and the environment is dying.

Humans' diminished concern for the environment is a result of the conceited notion that we have somehow surpassed nature, and have therefore made nature subservient to us. Since we no longer live 'outside', we do not have to suffer the consequences of our own actions. As a result, environmental education is not perceived as relevant in the modern era (Meadows, 1989).

The modern environmental movement often uses children to relay their message to the public. While this is seen to be affective, in reality it rarely is. This is mainly because the children involved are typically merely parroting the message of adults, and rarely understand the significance of their message. In addition, the adult audience rarely ever takes the advice of children seriously, but instead considers their child's speech to be a photo-opportunity (Hart, 1997).

Involving children in the environmental movement is a tactic that would have great potential if it were taken more seriously. "[C]hildren are more receptive to change and are less integrated into the existing economic system and social order" (Hart, 1997). Instead of relaying the message of adults, children should develop their own message, along with a thorough understanding of that message. This message should not be sent to adults, who will not take it seriously, but instead to other children, who will certainly listen to their peers.

Methodology

In order to determine the most appropriate design structure for the planned well at Heifer's Overlook Farm, we first needed to conduct a series of surveys and interviews with groups of people who were most likely to visit the well site. These surveys and interviews were conducted as a means to gather two types of data: 1) the extent of their knowledge of the global water situation, and 2) their opinions regarding specifics of the design structure that could be of advantage to us. In order to gather this data, these surveys and interviews were focused on different groups of people, including the Heifer staff, Heifer volunteers, and the Farm's visitors.

The two types of data were collected in two different ways. The first type of data, global water situation knowledge, was collected in a survey. We determined that a focus group interview would not be the most efficient tool for this section, mainly because those who are unable to answer a certain question are likely to quickly agree with another person who seems knowledgeable. The second type of data, design structure input, was collected with a focus group interview consisting of about 7 subjects at a time. We believed that if multiple subjects were allowed to brainstorm together, it would increase the likelihood of creating more and better ideas. These interviews were recorded on an audio tape to preserve the entire discussions in their original format, and to be examined at a later date. In order to ensure that the responses from the subjects are honest and uninfluenced, we did not allow anyone who had taken the survey to participate in the focus group interview.

Data Collection

The Global Water Situation

Since the well is intended to serve as an educational tool informing the public of the global water situation, it was important that we first determine the extent of the knowledge that the public has regarding the situation. More importantly, this helped us to determine the knowledge of which the public is *not* aware. This knowledge was taken into consideration when the well was designed, with the intention of using the well to inform the public about water across the globe.

This survey included quiz-like questions that do in fact have correct and incorrect answers, however the subjects were not be aware of this. The subjects were told that the questions are in no way intended to evaluate their intelligence, in order to reduce their level of anxiety. The subjects were also told that there are no correct answers to the questions (even though in many cases there were), in order to gather more honest responses. The subjects were asked to give rough estimates or guesses in response to questions regarding the global water situation.

The questions in these surveys were primarily close-ended and focused on several different aspects of the global water situation, including water scarcity, water pollution, and geographical questions. The questions helped us to determine how much they knew and how serious they considered the global water situation to be. Depending on the findings of these questions, the information displayed at the well site may be presented in varying degrees of bluntness or subtlety, with the less common knowledge presented in a more direct manner.

The Design Structure

In order for the well to serve its primary purpose, it must be not only informative but also interesting. To determine what the public would consider 'interesting', the interviews we conducted included open-ended questions asking for the subject's input about what the well could include that would catch the public attention. The actual format and content of these questions varied depending on the subject; for example, if the subject is a child, the word 'interesting' may be replaced by the word 'fun'. By doing this, we hoped that the well could be designed in such a way as to attract and sustain as much attention as possible.

In order for the well to attract the public, it must appeal to them in a personal manner. This interview focused on determining what the well could provide that would be appealing to its audience. This section also included open-ended questions asking the subjects for their input regarding ways in which the public could be involved in the use of the well. We believed that if the audience has some hands on experience with the well, they would be more likely to understand its significance.

Well and Site Design

In addition to gathering data through interviews and focus groups, we also gathered data about the well site, its surrounding environment, and the aquifer it will tap. The first step in obtaining this information was to locate an existing nearby well. This well would tell us almost everything we will need to know about the aquifer, including water depth, water quality, and aquifer material. If there were no preexisting wells with which to obtain this data, we would have made a test well near the proposed well site and collected data from it.

With the data we have collected, we followed the well design principles outlined in the literature review. Thus we determined possible values for well measurements, materials, and designs. Next we used the results of our interviews and focus groups to create several potential site designs, including the well, the pump, and any additional things.

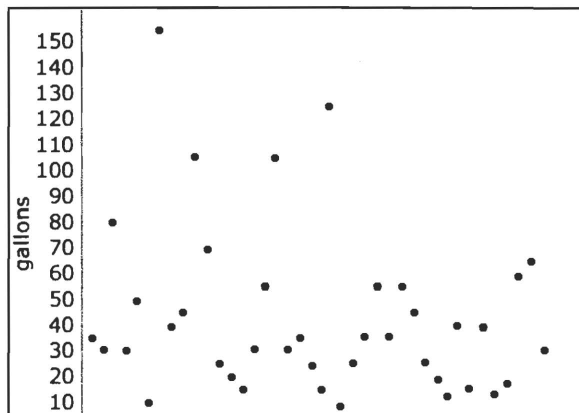
Upon completion of at least three possible designs, we presented the designs to the Heifer staff. The presentation had the pros and cons of each design, approximate pricing, visual examples, and other pertinent information. Heifer then had the opportunity to select a design for their well site. Once Heifer had made their final decision regarding their choice of design, we drew up a detailed plan that will contain all information necessary for the well site to be constructed.

Results

Survey Results

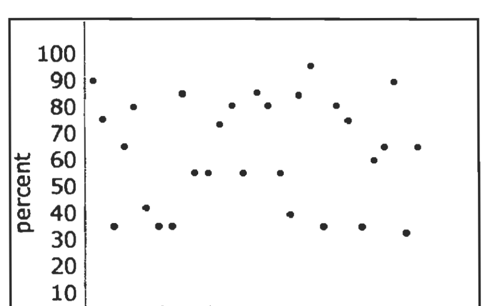
We administered our survey over the two days of the Heifer International Fair, June 28 and 29. We recieved a total of 43 responses (see Appendix 1 for survey questions and Appendix 2 for survey data). The number of responses per question varies, because we did not require that all questions be answered. A large majority of respondants were over 50, and only 9 were male. The results show, as we expected, that most people know very little about the global water situation. Despite this support of our general hypothesis, there were several questions that yielded surprising results.

Question 4 asked for an estimate of the amount of water the average person in North America uses each day. The correct answer is 100 gallons, and while we expected respondants to underestimate, we were surprised at the degree of underestimation. As you can see in the graph at right, only two people were correct and only two overshot (The yellow line indicates the correct answer.). The average of all responses is a mere 37.575 gallons, and while low from our perspective, it is still nearly 10 times more than the average water used per person in developing nations.



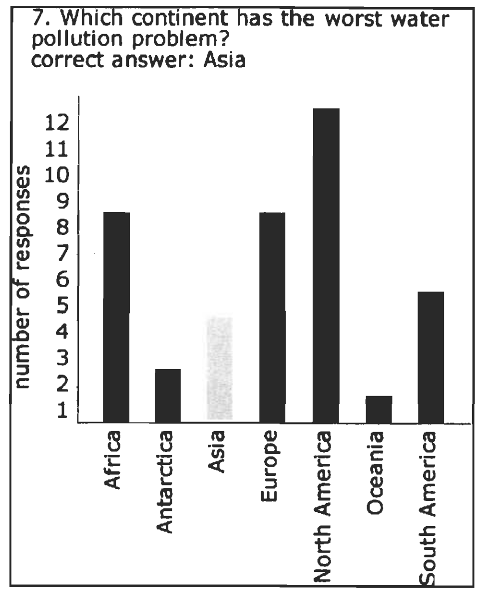
4. How many gallons of water per day does the average person in North America use?
correct answer: 100 gallons

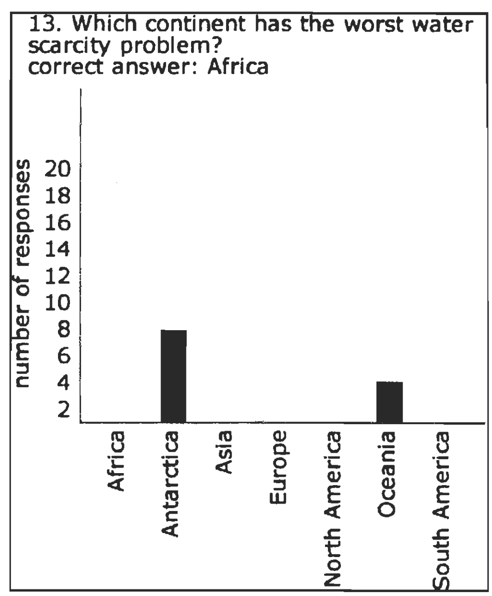
Question 15 posed a similar question, asking for the rough percentage of the population



without access to safe drinking water. This time the results were reversed; no one underestimated, only seven were accurate, and the average of 64.3% is well above the correct answer of 20-35%.

Questions 7 and 13 were very similar to one another. The former asks which continent has the worst water pollution problem, and the latter which has the worst water scarcity problem. The correct answers are Asia and Africa respectively. Respondants did well with question 13; more than half were correct, and those who were not spread their answers over only two options. Question 7 was not so easy. Only four respondants were correct, and Asia was the fifth of seven in its number of responses. Of an equal surprise was the fact that North America was the most popular choice. Upon talking to some of the respondants however, we discovered the source of the problem. In our research and therefore in our survey, water pollution is measured by the population's access to sanitation. Those taking the survey were unaware of this detail and assumed that water pollution is measured by the amount of industrial pollutants in rivers, lakes, etc (this is actually impossible to measure, hence the measure of sanitation). While North America does have rampant water pollution, it

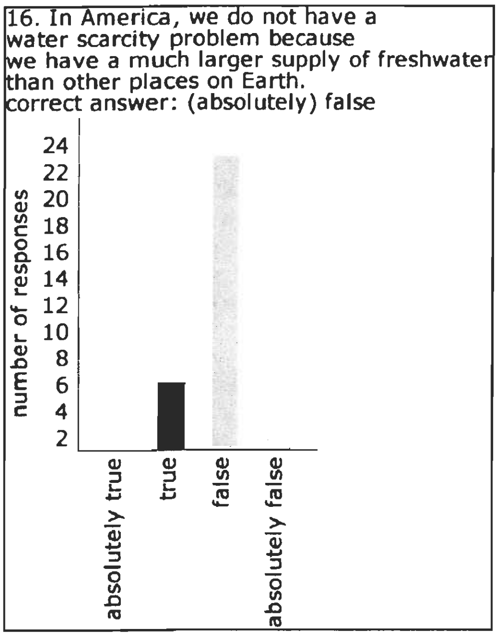


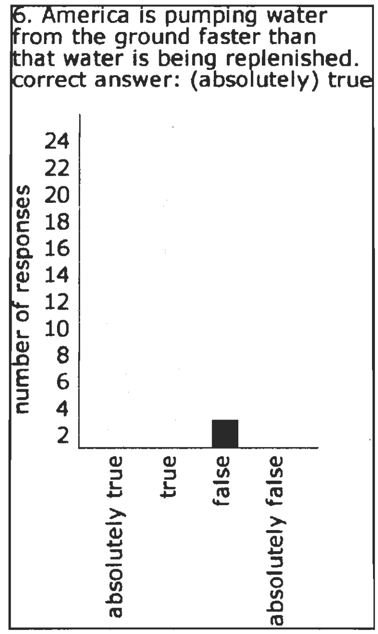


also has the facilities to purify the water before its distribution to the public. It was surely this miscommunication on our part which led to the unexpected and muddled results.

Questions 8 and 9 asked how serious they thought the water pollution problem is, first across the globe, and then in their state (both on a five point scale, five being most severe). The state one lives in is really irrelevant in this case, because they are all part of North America which has 100% access to sanitation, making them generally the same in comparison with other parts of the world. Based on our research, our answer to these questions would be 5 for global and 2 for state. What we found, however is that while people on the whole consider water pollution to be very severe worldwide, they believe the problem in their state is almost as severe. On average, the response for state severity was not quite one point less than global severity. This leads us to the conclusion that while people know there is some sort of problem, they really have no idea how serious the global water situation really is.

One of the few glimmers of hope we found were in questions 6 and 16. Both are true/false questions where respondants were overwelmingly correct. The first stated "America is pumping water from the ground faster than that water is being replenished." This is a true statement which allows us a glimpse into a future with no water left to pump. Only two respondants answered false. The second question said "In America, we do not have a water scarcity problem because we have a much larger supply of freshwater than other places on Earth." This statement is false. Every continent has roughly the same amount of freshwater underneath it. Water scarcity stems from an inability to get to that water, a problem potentially caused by many factors. Once again the respondants did well. Only five answered incorrectly. These two questions indicate that the public has at least some concept of groundwater problems. This is key because it gives us a starting point – a place to begin education.





Focus Group Interviews

On Thursday, July 3rd, we held two focus group interviews. The first group included members of Heifer's staff and full-time volunteers. The second group included younger part-time volunteers. Both groups were given the same set of questions. The groups were told to engage in a discussion amongst themselves in an attempt to answer each of the given questions (see Appendix 3 for transcripts of the interviews).

Staff and full-time volunteers:

When asked what the well could provide that would be appealing to its audience, the first group provided multiple suggestions, including the following quotes: "something moving... something they can participate in"; "they can get water from it"; "on the tour they could pump water".

The next question asked their opinion of a text display (e.g. a sign) with information about the global water situation. The first group had mixed opinions. Some members had no objections ("No, I think it would be a good idea."). Others were hesitant about affecting the visual theme of the global village ("The only objection... is that we try not to have a lot of signs out there... we like it to look more realistic... not 'in your face'.") One member suggested a "notebook that you open up and read about". The benefits of a notebook would be a virtually unlimited amount of space with little to no effect on the visual theme of the well. In the end, the group concurred that some type of text information would be beneficial, though a sign would have a negative visual effect on the theme of the global village.

The next question asked for suggestions regarding ways in which the audience could be involved in the use of the well. The group noted the importance of having the audience relate their experience to global water scarcity. One person suggested a type of regulation system that would cut-off water flow after a certain point, possibly preventing the user from extracting as much water as they needed (and, thus, relating to water scarcity). Another person noted that such a regulation system could hinder Heifer's staff and volunteers from doing their chores. At one point, the discussion came to the safety of drinking the water from the well. Since the water most likely will not be safe enough to drink, one person suggested a "reservoir... a water tank... filled with tap water from a hose" and went on to explain a system of two water tanks, one filled with water pumped from the well and one filled with tap water; the tap water could be used for human consumption and the well-water used for animals or other purposes.

Next, we asked the group for their opinions on a well in the form of a ride-on toy, such as a seesaw or a merry-go-round. The group's opinions on this were generally negative: "too fun and commercialized"; "what message would that be sending?".

Next, we asked for the group's opinions on a well that was pumped using energy from animals, rather than humans. One person noted that this would fit Heifer's theme, "That is one of the things we talk about: how animals are improving peoples' lives." The group noted that it would be important for humans to also be able to pump it, "even if it took six people."

Younger, part time volunteers:

When asked what the well could provide that would be appealing to its audience, the second group also provided multiple suggestions: "if it was designed in an unusual way... made with old soda bottles"; "recycled material"; "if the only way to get water out was to lead a goat around in a circle". The group showed a fondness toward "bucket-wells", though they also noted the safety risks associated with them (small children could fall down a well with a hole as large as a "bucket-well").

The next question asked the group for their opinion on a text display. Generally, the group was in favor of such a display. One person suggested that the statistics could be updated after a period of time, to show how the situation is changing ("as time progressed, people would see: 'Is it improving? Is it not improving?'").

Next, the group was asked for their suggestions regarding ways in which the audience could be involved in the use of the well: "a lucky-penny well". Most of the group's suggestions involved giving the pennies that were thrown in to a charity organization.

The group was then asked for their opinions on a well in the form of a ride-on toy, such as a seesaw or merry-go-round. The group seemed very enthusiastic about this: “oh that's so cool”; “that's a good idea”; “a merry-go-round might be a little silly”.

Next, the group was asked for their opinion on an animal-powered well. The group seemed to approve of the idea, and their discussion focused more on what type of animal would be used (“hamster”, “goat”, “water buffalo”, “yak”, “guinea pig”).

Presented Options

Discussion of Data

The survey analysis had shown us that generally, people tend to overestimate the local water problem and underestimate the global water problem. We also discovered that while most people have an awareness of the problem, they do not consider it during their daily lives. One of the main things we needed to convey to the public is the great extent to which we are better off than other parts of the world. At the same time, we must also express the importance of conservation; despite the low severity of this country's problem, we must continue to take steps and precautions to keep the threat level low.

The first focus group made it clear that the well needs to be 'hands-on.' This ruled out all automatic pumps, which make up the majority of well pump options. They also expressed a desire for the site to look realistic, therefore we narrowed the search further by only including pumps that are used in the developing world. Another request was for the pump to not be an old American handpump or a ride-on toy.

Because the nature of a well is more closely related to water scarcity than water pollution, we chose to focus more on the water scarcity issues. Since water scarcity is worst in Africa, it made sense to choose a well design that is popular on that continent. Of the various handpumps looked at, we chose the Volanta for many reasons. First, it is rapidly gaining popularity in Africa, with over 10,000 pumps installed in countries such as Niger, Mozambique, and Burkina Faso. Second, it has a unique flywheel design that is simple, easy to use, and aesthetically pleasing. In addition, it is quite resilient, with easy installation and minimal maintenance. The Volanta is only manufactured by one company, based in Holland, which offers it for a reasonable price.

For our next design option, we chose not to limit ourselves to only one continent. From a list of the most popular human powered pumps in the developing world, we first eliminated pumps which required a trained team to install and then pumps made of materials that are not corrosive resistant. This left us with four pumps: Afridev, Tara, Rower, and Vergnet. From there we eliminated the Vergnet because it uses a foot pedal pump that is difficult to use, especially for children. Next we eliminated the Rower because it operates on an incline and therefore requires considerably more space than the others. Between the two remaining pumps, we discarded the Tara because it is small, unimpressive, and less likely to be appreciated. This left us with the Afridev, which is cheap and easy to install. It has been in use for many years in Asia, Africa, and the Middle East.

Both focus groups liked the idea of an animal powered pump. One group noted that it fit well with Heifer's theme, so we chose this type to be one of the options. It was also said that any animal powered pump must also permit usage by humans, a detail we kept in mind. After extensive research into animal powered pumps, we found a single company who produces one, the horse rope pump. Although very inexpensive, this pump is difficult to install and the company recommends having a trained team to do so. Unfortunately, this company is based in Nicaragua. Despite its name, the pump can be powered by donkey, horse, camel, or any other work animal.

Based on their suggestion to use two tanks, one with tap water and the other with groundwater, we made it an option. One drawback of this setup is that the site design would become much more difficult. Instead of merely purchasing the system for simple installation, we would need to draw up an elaborate piping scheme which would considerably raise the cost, size, and complexity. The other possibilities were to use only the groundwater from the well or to use only tap water from Heifer's main water supply.

Assuming an option using groundwater is selected the well needed both casing and a screen. According to the Massachusetts Water Resources Authority (http://www.mwra.state.ma.us/) the area groundwater contains iron and is potentially corrosive. For these reasons, as well as its low cost, we recommended PVC as the casing material. Because the well will be naturally developed and shallow we recommended cutting slots directly in the casing. This combination will keep the casing and screen from needing frequent replacement.

Options

Volanta Pump

Our first option is the Volanta pump. This pump is becoming widely popular in developing countries in Africa, including Burkina Faso, Mozambique, and Niger. It has a unique design which makes it easy to use and virtually maintenance free. Also, it is easy to install without using any special equipment. Because it is built to withstand the harsh conditions of Africa, it has reliable construction and lasts for many years.

The Volanta pump has a large steel flywheel that when spun causes a pump rod to move up and down. The verticle pumping action brings water up and out thru a tap. It is designed to work with either dug or driven wells 10 – 100m deep. Jansen Venneboer, based in the Netherlands, is the only company that produces the Volanta. Their standard price for the pump is €1,342 (approx $1,522), excluding taxes and shipping.

This pump has the potential to be dangerous if someone were to carelessly slip their arm in the flywheel as it is spinning. Another disadvantage is that some masonry work is required to make the pump base. Despite these two drawbacks, the Volanta is an efficient and reliable pump that has proven itself throughout the developing world.

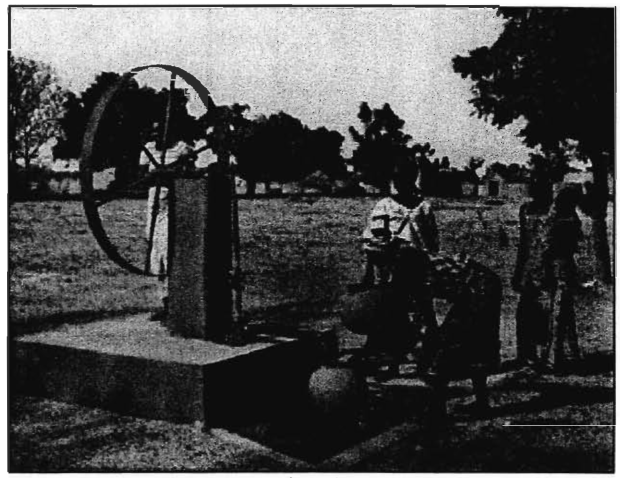


Image taken from www.handpump.org

Afridev Pump

The second option is the Afridev pump. This pump meets all VLOM (Village Level Operation and Maintenance) standards, and is widely used in African and Asian nations, such as Pakistan, India, Kenya, and Mozambique. It is easy to install and operate, and is very reliable, but masonry work is usually needed.

The Afridev is operated using a simple lever, and water is pumped out of a small spout. It can be used in all wells from 10 – 45m deep. Because of its wide popularity, there are many companies that produce this pump. The price varies by supplier, but is usually less than $1000.


Image taken from http://lifewater.ca/

Horse Rope Pump

The last option is the Horse Rope Pump. It is the only animal powered pump being produced for sale. This is because animal powered pumps are slowly being phased out. They are much less efficient than human powered or mechanized pumps, and they are being systematically replaced throughtout the developing world.

The Horse Rope pump is a variation of the Rope pump, which operates using a pulley system to raise water via an endless rope with pistons attached. In this variation, a horizontal gear is added which allows the power to come from a work animal walking in a circle. The Horse Rope pump has been successfully used in wells up to 70m deep.

The company who makes the Horse Rope pump, Aerobombas de MECate (AMEC), is based out of Nicaragua. They recommend having a trained team to install the pump, because it is difficult, but once installed little maintenance is needed. The cost of this pump is about $390.

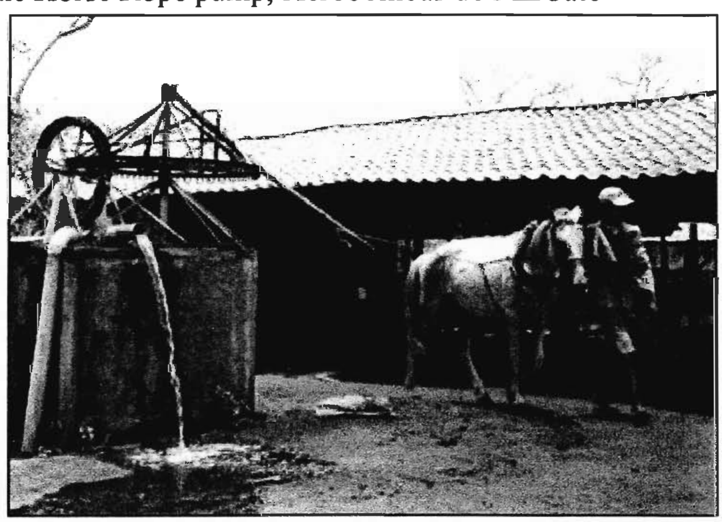


Image taken from http://home.planet.nl/~holts000

Ground / Tap Water Option

As for the water that the planned well will pump, three options exist. The first, more obvious option is to pump groundwater. The second option is to connect the pump to Heifer's already existing water supply, which would guarantee that the water would be safe to drink. The third option is a combination of both: to pump both groundwater and tap water; this option may require a system of water tanks or reservoirs that could either be installed above or below ground.

While pumping groundwater seems like the obvious solution, it has many drawbacks. Most importantly, this groundwater will almost certainly not be safe enough for people to drink. While that may not seem like an issue now, it will be important to make sure that all staff, volunteers, and visitors are aware of this; otherwise, they might assume it to be a drinking fountain. In addition, there is also the possibility that the water is so unsanitary that it could not be used for any purpose, let alone drinking. Typically, the deeper the water source is, the more likely it is to be sanitary. If the water is where we expect it to be (10-20 feet below ground) there is a very small chance of it being clean. Second, since we have not yet verified the exact depth or location of the water source, it is possible, albeit unlikely, that it is not there. If the water source is there, there is the possibility of it drying up in the future, which would render the pump useless.

The second option, while it may be less impressive, is to instead attach the pump to Heifer's existing water supply, which has already proven itself to be sanitary and reliable. This would also allow the pump to be placed anywhere. Depending on the water system, this could be very simple to build, requiring only some extra pipes, hoses, and valves. However, it is possible that this will also require a water tank or reservoir, which could be installed above or below ground. The reason for this lies in the difference in water pressure: a well pumping groundwater is working against the force of gravity, whereas a pump connected to the tap-water system with be working with that system's pressure. This means that the water pressure from the tap will have to be stopped, either by filling a water tank or by another means. Despite the added parts, this system is likely to be more reliable than a groundwater system.

The third option is a combination of the two: a system that pumps both groundwater and tap water. For such a systems as this, there are many possibilities. Two separate pumps could be used, which would lessen the likelihood that a water tank would be needed. Using only one pump could be complicated, since the groundwater and tap water should not ever pass through the same pipes. Depending on which water – tap or groundwater – will be discharged by using the pump, another faucet of some sort may be needed to discharge the other water. As with the previous option, this system has many possibilities.

Presentation of Options and Feedback

We presented our options to Heifer on July 22, 2003 (see Appendix 4 for slide show). It was our expectation that after we presented the options, we would be provided with Heifer's selections so we could draw up the final plans. Unfortunately, this was not the case. Immediately following our presentation, we engaged in a long discussion with the Heifer staff and volunteers. Instead of making a decision, they requested additional information, some being on subjects we had not previously researched.

They seemed to react positively to each of the three pumps we presented, however it seemed from the conversation that the horse rope pump was generally the least favorite. The Volanta pump appeared to be the favorite of those who were present, but the cost was an obvious problem. They discussed the possibility of a donation, but no decisions were made.

Another cost that was brought up by our audience was the price of drilling the well. We agreed to obtain price quotes from various drilling companies in the area. Upon talking to these companies, we found that no one will come in to drill a well that is only 20-30 feet deep. This supported our research, which showed that shallow wells are generally driven or hand dug. This method is much more inexpensive and does not require contractors.

There was a lot of deliberation regarding our groundwater or tap water options. There was a definite push by some staff for the well to yield groundwater. There were also some dissenting opinions present, including ours, citing the high probability of unusable water (due first to the shallow location of the aquifer, and exponentially increased because it is located on a farm). Heifer's conclusion to this argument was for us to research low-tech filtration devices that could be used at the well site. We have found many filters that claim to kill 99.9% of all water-born bacteria and disease, but we are also still hesitant to believe that they will safely purify what has the potential to be very polluted water.

After completing our extra research, we again talked to Heifer. We were unable to obtain a specific budget, but they put an approximate cap at $1000. They also had selected the Afridev from the three pump choices and were enthusiastic about our suggestion to drive the well. At this point our only remaining step was to draw up the final recommendations.

Final Recommendations

Pump

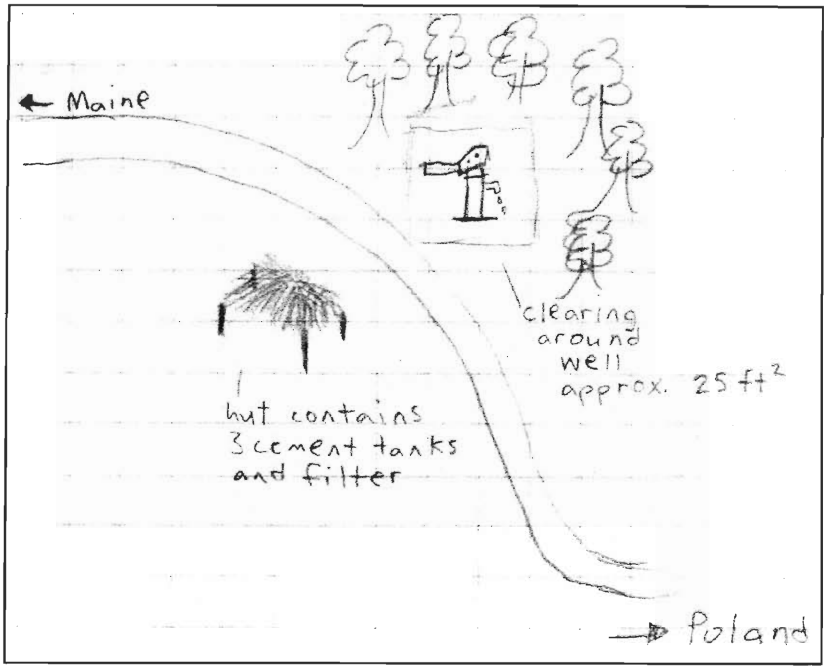
After the options were presented, Heifer chose to use the Afridev pump. This particular pump is one of the most widely used in developing countries, mainly because of its ease of installation and use and its reliable construction. While it has many qualities on par with another option, the Volanta pump, the Afridev is around one third of the Volanta's price and is sold by many manufacturers worldwide. For these reasons and more, Heifer found that the Afridev pump was the most suitable option.

Filter

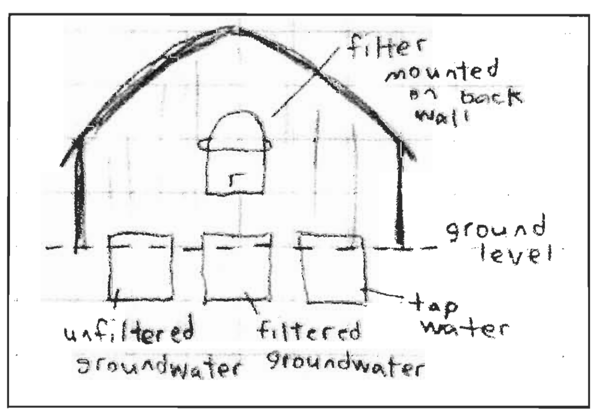
The filter we chose for the well site is the Katadyn Drip Gravidyn Water Filter. This filter produces approximately one gallon of pure water per hour, and is powered by gravity, which makes it a good choice for the global village. It uses three combined ceramic and active carbon filters for thorough filtration of chemicals, bacteria, and other water-borne diseases. Replacement cartridges are not needed, as the ceramic can simply be cleaned with an abrasive pad.

Well Site

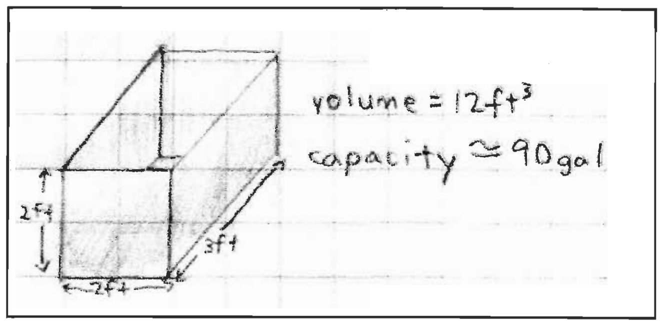
In addition to the pump and filter, our recommendations for the well site include a hut and three in-ground tanks made of cement. These will be located across the path from the well site.



The hut will be similar to the hut located at the Kenya/Uganda site in the global village. Since the Afridev pump is used in Kenya, this hut design would be very appropriate. Since this hut will not be located at the well site, it will not cover the pump. Instead, it will cover the three cement tanks and the water filter. The purpose of the hut will be to provide shelter to persons who are filtering or retrieving water from the tanks and to prevent rainwater from entering the tanks. The hut will also enhance the visual theme of the site by showing how an actual well site in Africa might look. The hut should have only one wall, in the back, on which the filter will be mounted. The front and sides of the hut will be open. The thatched roof should be made of straw or similar material, and should be held up in the back by the wall and in the front by two wooden poles.



Along with the water filter, the three water tanks will be located beneath the hut. Each tank will hold a different type of water: unfiltered groundwater, filtered groundwater, and tap water. While we refer to them as "tanks", in reality they are nothing more than a hole in the ground lined with cement. The top of the tanks will be left open so that people may scoop water from them. When the tanks are not in use, they may be covered by a wooden "door", which could be as simple as a piece of plywood. These tanks should be 2ft wide, 3ft long, 2ft deep and can easily be hand dug. Each tank will have a volume of 12 cubic feet and a capacity of almost 90 gallons. The use of cement and wood for the water tanks will fit the visual theme of the well site, since in-ground reservoirs in developing countries are typically lined with stone or cement.



A person will retrieve water from all three by scooping it out with a bucket or pot. The first tank, unfiltered groundwater, will be filled by pouring in water pumped from the well. Whenever the need for filtered water arises, someone will scoop up some unfiltered water and pour it into the filter. When filtration is complete, that water should be poured into the second tank. Or, to automate this process, a hose can be hooked up from the filter to the tank. The third tank, tap water, will be filled by a hose with an on/off valve. This hose will be connected to the main water supply at the Overlook Farm, and is the *only* tank from which people can drink.

Gathering the Materials

Afridev Pump:
Ajay Industrial Corporation
http://www.ajayindcorp.com
Mr. Akhil Jain
4561 Deputy Ganj, Sadar Bazar
Delhi-110 006, India
Phone: 011-91-120-4770679/4770233/ 4770339
011-91-11-3545291
Fax: 011-91-120-4770629, 91-11-3536205
E-mail: ajaypump@mantraonline.com OR info@ajayindcorp.com

PVC Pipe:
Diameter = 3in
Length = 20-30ft
Available at Home Depot, Lowes, etc.

Steel Driving Pipe:
Length = 5ft
Diameter = 3in
Manoog Chas Inc
9 Piedmont St, Worcester
Phone: 508-756-5783
$4.19/ft

Mason:
Everlast Masonry
80 Dorchester St, Worcester
Phone: 508-757-5994

Filter:
Katadyn Drip Gravidyn Water Filter
$265
www.outbackgear.com
Phone: 1-888-311-CAMP

Making a Well Screen

At the bottom end of the PVC pipe, plug up the hole with about three inches of cement. This will ensure that sediment does not enter into the well. Next, "using a hack saw, cut slots in the plastic casing which are as long and close together as possible. Slots should be spaced as close together as possible vertically and should extend about 1/5th the circumference of the pipe; there should be 3 even rows of slots extending up the pipe separated by 3 narrower rows of solid, uncut pipe (for strength). (Lifewater Canada, 2003)"

Driving the Well

To construct a tripod for manual driving of the well, first arrange three 10ft wooden poles in a teepee fashion. Nail the poles together at the top where they meet. Next, nail a wooden 2×4 horizontally across two of the poles approximately 7ft high. Attach a pulley to the crossbeam. Tie a rope to the top of the driving point (a steel pole with a pointed end), thread the rope through the pulley, and tie the end to a tree. "To obtain the reciprocating motion a crew of 4-6 men line up facing the rope and alternately pull down and release the rope in unison. (Koegel, 1985)"

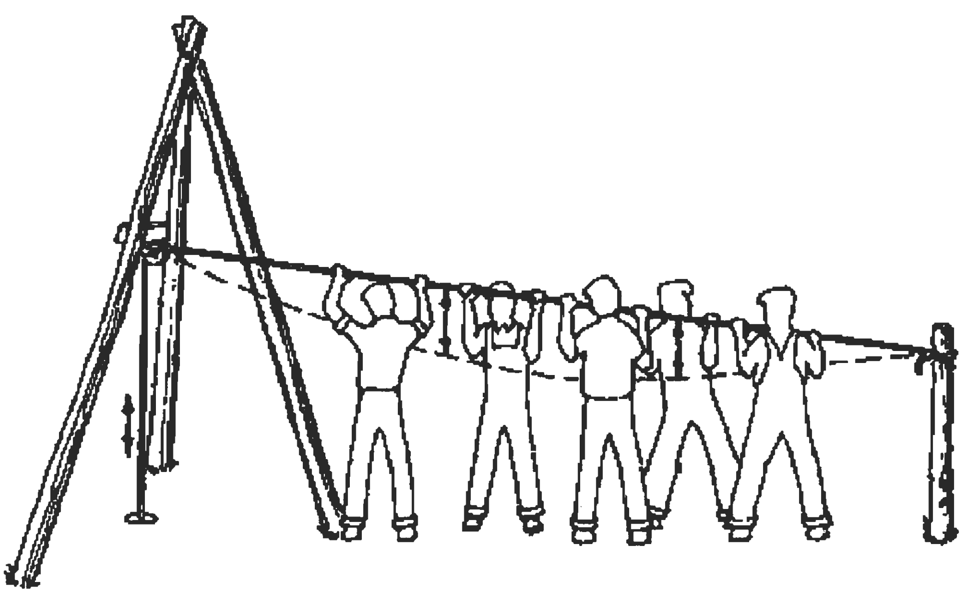


image taken from Self-Help Wells

Appendix 1 – Survey Questions

Water Survey

Directions: Please answer the following questions in the order that they appear. For all multiple-choice questions, circle your answer. For all fill-in-the-blank questions, write your answer on the lines given. For all True/False questions, if you are certain of the correct answer, you may answer Absolutely True or Absolutely False. If you have any questions, feel free to ask one of the 2 students who are wearing the 'WATER' name-tags.

Thank you very much for your help. Jen Peters, Shaun Calhoun

Gender: M) male F) female
Age: ______________ years of age

1. Will America run out of freshwater someday?
   A) very unlikely B) unlikely C) likely D) very likely

2. In America, we have to pay more for water than in poorer countries.
   A) absolutely true B) true C) false D) absolutely false

3. Where do you think your tap water comes from? ______________________________
   ____
   ____

4. The average person living in sub-Saharan Africa uses 2-5 gallons of water per day. How many gallons per day does the average person in North America use? ___________ gallons

5. It is safer to use water from an underground source than from an aboveground source, such as a lake or stream.
   A) absolutely true B) true C) false D) absolutely false

6. America is pumping water from the ground faster than that water is being replenished.
   A) absolutely true B) true C) false D) absolutely false

7. Of the 7 continents, which do you think has the worst water pollution problem?
   A) Africa B) Antarctica C) Asia D) Europe E) North America F) Oceania G) South America

8. Across the globe, how serious of a problem do you think water pollution is? (on a 5-point scale)
   1) not serious 2) 3) somewhat serious 4) 5) very serious

9. How serious do you think the water pollution problem is in your State?
   1) not serious 2) 3) somewhat serious 4) 5) very serious

10. Historically, there was a specific period of time when water pollution started getting much worse very quickly. When was this time?
   A) Renaissance B) Agricultural Revolution C) Industrial Revolution D) World War 1 E) Roman Empire

11. List as many things that you can think of that pollute water. ______________________________
   ____
   ____

12. Do you know how to tell if your water is polluted? Y) Yes N) No
If yes, how? ____
____
____

13. Of the 7 continents, on which do you think people have the hardest time finding water to drink?
A) Africa B) Antarctica C) Asia D) Europe E) North America F) Oceania G) South America

14. Across the globe, how serious of a problem do you think water scarcity is? (on a 5-point scale)
1) not serious 2) 3) somewhat serious 4) 5) very serious

15. In your opinion, what percentage of the human population on earth does not have access to safe drinking water?
__________ %

16. In America, we do not have a water scarcity problem because we have a much larger supply of freshwater than other places on Earth.
A) absolutely true B) true C) false D) absolutely false

17. a) How much of an effort do you make to conserve your water use? (on a 5-point scale)
1) no effort 2) 3) some effort 4) 5) as much effort as possible
b) If you do make an effort, how do you conserve water? ______________________
____
____
c) How much of an effort does your family (not including you) make to conserve their water use?
1) no effort 2) 3) some effort 4) 5) as much effort as possible
d) If your family does make an effort, how do they conserve water? ______________________
____
____

18. a) Approximately how often do you shower? ______________________
b) Approximately how long are your showers? ______________________ minutes

19. a) Do you know what this phrase means: "If it's yellow, let it mellow. If it's brown, flush it down."?
Y) Yes N) No
b) If you answered 'Yes', do you practice it?
Y) Yes N) No

20. If you had to start conserving more water, what would you start doing? ______________________
____
____
____

21. a) What have you been taught about water scarcity and pollution? ______________________
____
____
____
____
b) Were you taught about this at school or elsewhere? ______________________
c) Approximately how old were you when you first learned about these problems? ______________

Thank You!

Appendix 2 – Survey Results

day	sex	age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17a	17b	17c	17d	18a	18b	19a	19b	20	21a	21b
				c or d	aquifer	100	a or b	a or b	c			c		need proper equipment	a		20-35	c or d											
sat	f	12	a	b	either a well or aquifer	5 or 6	c	c	e	4	3	c	oil, garbage, boats	n, i think if it smells, has any coloring, or makes you sick	f	3	30	c	3	make sure taps are not running when not being used. do not pollute	3		every other day	30	y	n	drink less water, dont flush, take less showers	nothing really	no
sat	f	17	c	b	well water in shirley , ma	10		b	d	3	3	c	factories, car exhaust, ozone layer	n	a	4	75	c	2	shorter showers	2		every morning	10	n		shorter showers , less water wasted for dishes	earth science class, farm videos- pollution in africa, europe, etc	school and farm
sat	f	18	d	c	reseviors, wells	20	b	b	a	4	4	a	oil, trash, waste from factories	n	a	4	50	c	3	short showers, dont let tap water run, dont let hose run	3	being careful about the hose and tap water use	every day	10	y	y	catch rain water, waste less water	it is becoming and has been a big problem. how people who use water often become sick from not filtering it	school , hpi
sat	f	19	d	d	well	50	b	b	g	5	5	b	farms, factories, toothpaste, sewage, acid rain	n															
sat	f	29	c		reservoir	10	b	b	a and c	5	5	c	chemicals, exhaust, humans (waste)	n	a	5	80	c	3	turn of water when brushing teeth, do full loads of laundry fill sink with			every 36-48hrs	10 to 15	y	y	i dont know		high school

																				water not run water to do dishes, recycle, shower quickly, not daily (except summer)									
sat	f	38	c	c	reservoir	20-30	not sure	b	g	5	3	c	pesticides, animal and human waste, household and lawn products, etc	n	a	5	25-30	c	4	brick in the toilet tank, water only plants as they need it, not letting tap water run, water conservation shower head, short showers energy efficient washer and only run dishwasher when full	4	as above	daily	5 to 7	n, but i can guess	sometimes	not sure	formally taught very little but have picked it up along the way	no
sat	f	40	c	c	reservoirs	20	c	b	e	4	4	c	agricultural chemicals, industrial waste, sewarage, acid rain	n	b	4	50	c	3	use dehumidifier water for laundry, set washerwater level, monitor personal water use (showers,etc)	3	as above	every other day	10	y	n	less laundry, let yard go with only rain	hard to answer this- in 40 years you pick things up here and there	both
sat	f	42		c	the well in my yard	40	c	b	e	5	3	c	chemicals, bacteria, drugs	n	a	3	30	b	3	turn off water when brusing teeth, washing dishes etc, take baths, dont water grass	3	same as above	every other day	10	y	y		the water on the planet now is all we'll get	on my own-reading

sat	f	43	b	c	reservoir	150	c	c	g	3	2	c	industry, fertilizers and farming, pesticides, acid rain	y, have it tested	a	3	70	c	4	only run water when actually using it, water restricted showers, run dishwasher only when full	3	same as above	daily	15	y	n	shorter showers, less water wasted for dishes	our water is cleaner now than 100 years ago	elsewhere
sat	f	44	d	c	oradell reservoir	120	both unsafe	a	e	5	5	b		y, if birds and bees wont drink it, with tests for contaminents	a	5	69	c	5	rain catchers, low pump toilets, faucets, etc	3	fewer baths, short showers	1x day	2	y	occasionally	stop baths, wash fewer clothes less often, recycle grey water	everything	elsewhere
sat	f	48	b	a	rain	25	c	a	f	5	5	b	coal, mills, farms, cities, boats	test water life	b	5	50	b	3	dont flush every time, dont run water, water garden early and late, catch rain, dont water grass	4	as above	daily	15	y	y	catch more rain, better garden water system	not much	elsewhere
sat	f	49	c	d	underground aquifer filled from rain and snow melts	35	c	a	e	5	4	b	fertilizer, human and animal wastes, soaps, manufacturing by-products	n	a	4	75	c	4	have a low use washer, use water saver cycle on dishwasher, water saving shower heads, do not water lawn, use some water twice- like wash lettuce then use it to water	3	by my lead	every day	5	y	y	flushing less, hand washing dishes	it is a problem and my grandchildren may have serious problems	from reading and news

																				plants									
sat	f	50	d	b	wells	15	b	b	a	5	5	c	industrial waste, flouride, animal feces	n smell, color, taste	a	5	75	c	4	dont leave it running when i dont need to			every other day	5	n		shower less	most people dont care and netiher does industry	
sat	f	55	c	a	resv	25	a	a	e	3	3	c	industry, run off from roads	n															
sat	f	55	d	d	reservoir	30	b	a	d	5	4	c	man-made chemical, runoff from roads farms etc, pesticides, acid rain, flouride from air pollution and water flouridation, human sewage problems, animal waste	y, must get it tested	f	5	60	b	4	try not to flush so much try not to wash clothes too often, try not to let water run too much in sink	3	as above	2-3x week	15-20	y	y	shorter shower	not much other than what ive found out myself	just around, being aware
sat	f	61	c	c	streams from mts or underground springs	25	b	a	d	5	1	c	industrial waste, animals-beaver, chemicals used on crops and vege, road salt, exhaust, acid rain	y, get a kit from town and test it	a	5	50	c	3	shut off shower to soap, wash clothes in shower water	3	shower time, not run water when brush teeth	3x week	15	n		not run dish water-use container		elsewhere
sat	f	70	b	c	springs/delaware water group	45	b	b	b	4	3	c	people, manufacturing, animals, chemicals	n	b	4	55	c	3	brush teeth with water off, fix leaks	3	same as above	2x week	5 to 7	y	n	the above	more is taught in ads when there is a drought	elsewhere
sat	f	72	d	c	wells	30	d	a	d	5	5	c																	
sat	f	85	c	b	aquifer	3	b	b	e	3	3	c		n, illness		5	50	c	3	turn off faucets-wash			5x week	10	y	y			

																				dishes only when washer is full									
sat	f	40+	c		reservoirs=rain + ground water	100	b	b	e	5	4	c	car fumes, industrial wastes, household wasts, etc	n	a	5	90	b	1		1		once a day	20	y	n	take shorter showers, turn off water when brushing teeth, not flush when it is yellow	nothing	no
sat	m	40	c	d	quohog	65	c	b		4	3		fertilizer, factories, ..., acid rain, salt	n	a	5	35	c	3	not watering lawn, limiting showers, not letting water run needlessly, ...	3		daily	6	y	y			
sat	m	48	b	c	a well	100	c	a	e	5	5	c	people, animals, machines	n															
sat	m	82	c	b	my water comes from a drilled well 700ft deep into rock. it is quite pure and is drinkable		b	b	a	5	3	c	manure, industrial waste chemicals, insecticides, herbicides, farm lubricants-oil etc, paints and stains, fertilizers, natural minerals like lead, radonnn, uranium	y, send it to a lab for testing															
sat	m	82	c	c	wells and filtered stream water	18	b	a	a	5	5	c	fertilizers, pcb's, industrial waste	n															
sat	m	84	d	d	my well	75	a	a	c	5	3	c	sewage, oil, fertilizer, pesticides, acid rain, farm runoff,	y, scientific test	a	5	85	c	4	reusing waste water (garden) not leaving			bath daily		h		as above		35

													mining(especially gold)							water running									
sat	m	50+	c	a	mother earth	many	b	b	e	4	3	c	humans, people	y, the color of water is not natural	a	5	80	c	5	use carefully	5	use taps carefully	twice	5			use taps carefully		in school and outside school
sat		50	c	b	i do not know	i do not know	a	b	c	5			wastes, bacteria	y, safe sources, transportation, sewage systems, if it is not treated	a	5		b	5	turn off taps	3	turn off taps	twice	10	n		use it for essentials only	world environmental day motto water 2 billion people are dying for it	no
sun	f	17	b	d	lake	5 to 10	d	a	g	5	1	c	gas	n	b	3								20					
sun	f	18	b	c	reservoir via water tower	10	c	b	a	3	2	c	household chemicals, industrial waste, sludge	n	a	4	60	c	3	short showers, dishes washing, fewer loads of laundry	4	same as above	3x week	20	y	n	more of the same	not much	school, family
sun	f	22	d	d		35	b	b	a	4	3	c	chemicals from household and industry, waste dumped there by people	n	a	4	75	c	4	dont leave water running eg when brushing teeth, taking showers instead of baths	3	quick showers, collecting rainwater to water garden	daily	5 to 10	n		?	water pollution/ scarcity is a growing problem- not only in poor countries. we waste water everyday - laundry, toilets, showers, etc. a lot of people arent even aware of the problems	school and documentaries on tv
sun	f	25	d	b	reservoir	25	a	a	a	5	4	c	factories, people, boats, n	n	b	4	85	c	4	flush toilet less, share showers, only wash	3		every other day	10	y	y	i dont know		

																				large loads, wash dishes by hand take less baths									
sun	f	34	c	c	reservoir	30	c	b		3	3	c	fertilizer, insecticides, sewage, chemicals from factories	y, water quality testing	b	3	30		3	reusing water to water plants, turning off water when brushing teeth, less flushing at our camp	3	same as above	daily	10	y	at our camp, not at home	less laundry	groundwater gets polluted from chemiclas seeping in, acid rain hurts lakes in adirondacks	both
sun	f	35	b	c	reservoirs/ground water	50	d	a	d	3	3	c	agricultural production, industrial production, storm water runoff, recreational vehicles, septics/sewage	color, odor, taste, chemical and biological tests		4	250	d	4	low flow toilets, 'yellow/mellow brown flush it down' dish washing, short showers, turn water off while brushing teeth, dont water grass	4	as above	5x week	2	y	y	?	water budgets, aquifers, western water problems	school
sun	f	37	d	c	a well near worcester sand and gravel	40	c	a	b	5	5	c	cars, human waste, pesticides, insecticides, soaps/detergents	n	a	4	30	b	3	no sprinklers for yard, smaller tank for toilet, limit sink use	3		3-4x week	15	y	y			
sun	f	46	c	d	water table refreshed by rainwater	14+	c	a	c and d	4	2	c	lead, organic material, industrial waste	n, testing w/ chemistry	a	4	35-40	c	2	turning off the faucet when scrubbing dishes, mellow yellow, turning off shower to scrub, recycling cooking water to water	12:00 AM	as above, mulching	daily	10-	y	y	difficult to know	very little	elsewhere

																				plants									
sun	f	52	c	c	as a cambridge resident- stony brook reservoir in lincoln /waltham, last two years mwra from quabbin	50-70	c	a	d	5	4	c	industry, sewage, agricultural run off of fertilizer/insecticides, air pollution = acid rain = change in ph levels, erosion of top soil	y, algae = +nitrogen, ag sta test kits, i acctually read my annual water report from the city	a	5	70	c	3	low flush toilets, limiting waste, limiting use, low flow shower			daily	6	y	n	#19 in a drought	i grew up using a dug well with limited capacity and have lived in areas where all fresh water was desalinated sea water, lobbied in the 70s for low flow standard	at home
sun	f	57	d	a	wachuset reservoir	20	b	a	e	5	5	c	chemicals	n															
sun	f	65	d	b	well fields and town leveys from worcester	55	c	b	c	5	4	c	acid rain, fertilizers, manure, storm drains, salt, autboard motors, jet skis, septic systems, clearcutting, crosion from development	send a sample to a lab															
sun	f	67	c	b	my own well	35	c	b	d	5	3	c	arsnic, bacteria, lead, other metals, volatiles(gas -oil, etc)	y, lab test															
sun	f	72	c	d	town wells and quabbi	12	b	a		4	3	b	phosphates, fertilizers, sewage, road salt, oil,	n	b	3	30	b	4	brick in toilet tank, washing dishes	4	same as above	1x week	7	y	n	#19		elsewhere

					n								gasoline							once per day, outside watering only occasionall y inthe evening									
sun	m	52	d	c	rain, under groun d spring s	6 to 8	c	b	g	3	1	c	human feces, insecticide runoff, removal of topsoil, tree and plant exterminatio n	smell, acid test, abnormal bacterial content															
sun	m	61	c	c	reserv oir	30	b	b	d	3 and 5	3	c		n															
sun	m	67	d	a	well	50	b	a	e	5	5	c	man, oil, waste	n	f	3	80	c	3		3	short showers , not flushing all the time	daily	10	y	y	redesign pluming systems		

Appendix 3 – Focus Group Transcripts

Group 1

Shaun: "The first question we have: is there anything that you guys can think of that the well could provide that would be appealing to its audience?"

Dale: "Something moving, something they can participate in. Something they might do."

Man: "Yeah, during the global village they can get water from it, overnight."

Dale: "Or even something on the tour, if they could pump water..."

Shaun: "The second part of that: what would you think about – if we had some kind of text or a sign on it that had any information about the research that we gathered: basically what the global water situation is, how serious it is. Would you have any objections to a sign or text being on it?"

Man: "No. I think it would be a good idea."

Dale: "The only objection I think about is – we try not to have a lot of signage out there because we really like it to look more realistic. That's something to think about. Would we want it there, or even in a notebook they could open up and read about – that's not in your face. We'd definitely put that information in the self-guided tour..."

Man: "I'm an advocate for adding the summary of your research into our ed program."

Dale: "Oh, definitely that."

Woman: "Yeah."

Man: "So if that's part of our ed program you might not even need a sign if we're looking for the realistic look out there on the well itself."

Dale: "Right."

Woman: "...self-guided tour..."

Dale: "I think that's kind of – we've got a little consensus here. We definitely want all the info we can get out of it and we want to include it in our program, whether it's on the well itself – as long as it's available elsewhere we wouldn't need it there."

Shaun: "The second question we have is: is there are ways you can think of that the audience could be involved in the use of the well? We thought that if they were involved in it they would be more able to understand the meaning of it."

Woman: "We could use peasant meals... overnight..."

Man: "How could we go deeper with that thought? ... If they use the well in the global village overnight and they know about the statistics, how can they combine those two and actually understand – I mean obviously it would be part of the debriefing, but is there any way that we can have them thinking about the stuff that they learned about the well while they're using it? Isn't that one of your questions?"

Shaun: "That's exactly what we're trying to do."

Dale: "... Don't make it too easy to access. So they'd realize scarcity in the value of water."

Man: "Yeah. While they're actually pumping the water."

Dale: "Yeah."

Man: "And not just thinking 'Oh this is hard to pump the water from the well.' But thinking about other people doing it around the world."

Woman: "It'd be interesting if there was a way – this may be really too complex – a way to have the well only be allowed to pump out a certain amount of water – in intervals? So ... and at a certain point you're not allowed to get anymore. And it would be like 5 or 10 minutes later before you were able to get more water, so that people couldn't just come and get however much they want, that it would be more like – I don't know. Is that even something you can do with a well?"

Shaun: "Are you trying to focus on water scarcity, there?"

Woman: "I'm just thinking that might make them think a little bit more. Like, all of a sudden – the water isn't still coming out."

Dale: "I can see they'd be real frustrated if our crew was up there trying to do chores..."

Man: "And there are probably other ways we can implement that thing – the fact that... rules that we can apply in the overnight."

Woman: "Well, I tried last year saying that Guatemala was the only group given water buckets. And you had to get water from Guatemala... but everyone would just take their pots and go get water anyway."

Man: "We could just say you're only allowed one or two pots of water because you need to share with the community and if you didn't do that the community would be upset... We can just do something like that."

Man: "What kind of well are we looking for? Is it a pump or a bucket?"

Dale: "They're gonna show us their design idea."

Man: "Do you have any potential answers to your questions?"

Shaun: "Well, we thought that one of the obvious ones was that they could pump it themselves. That would make them involved in it. Another one we were throwing around was if they had to carry water... Because one of the things we learned in Africa – a big problem is that they have to carry the water up to two miles. And that's a big problem because you can only carry so much water. Some people don't understand how heavy water is and how far they have to carry it."

Dale: "One of the things we do is make sure that they don't have easy carrying buckets."

Woman: "Yeah."

Dale: "Pots and pans... easy."

Woman: "And the... that they wash in, they always manage to... Instead of having a nice bucket..."

Dale: "The other thing we talked about is – are they actually going to be drinking this water? Because if it's only a 20ft. well it probably isn't going to be safe."

Shaun: "Right. I wouldn't take the risk."

Man: "What if they boiled it? That's what they did in Arkansas."

Dale: "Yeah, they could. But I'm not sure if every group would do it. That'd be something to think about. The other way we go do it is – we could run – I could see us having a well... then having a reservoir up there, of some type – like a water tank – and actually have that water tank be filled with tap water from a hose. And so they're pumping water for animals, or they're pumping water into the reservoir, but the water they're really taking for human consumption... So they're pumping into one but they take, for the meals... would be from the other. And that would be tap water that we know would be safe."

Woman: "What if they had their... you can use the global village... what if they had the..."

Woman: "That's not maybe realistic."

Dale: "I don't that would quite meet the board of health approval... It's something we could play with but they wouldn't be real keen on that idea. But I like the idea of using something water purification..."

Shaun: "Another thing we found: that some pumps actually have kind of children's toys that pump water. It's kind of a long shot but I just wanted to throw it out and see what you guys thought – like a seesaw or a merry-go-round that actually pumps water as children played on it."

Woman: "Ehhh, it's too, kinda, fun and commercialized."

Dale: "I've actually seen that in development organizations... The idea is that the well... and it really was... I don't know how common it is."

Shaun: "It's not very common."

Man: "In developing countries, you mean?"

Shaun: "Right."

Dale: "Yeah, this is designed for developing countries... because it really was effective and working, but I'm not sure why it isn't very common... I wouldn't be against it, but I'd like – if we could see other well designs you have."

Woman: "Yeah. I would be more – even though it is something that might be – for our purposes, what message would that be sending? You want it to be a... the idea of water have such a focus – to make it something fun might not necessarily be the right thing..."

Shaun: "One other thing is: some pumps also have – instead of people pumping them, they have animals. Like, they would attach a donkey or a camel to some kind of lever, and they would walk to donkey – or whatever – around a circle, and they'd use his energy – or her energy – to pump the water. How would you feel about that?"

Dale: "I could see it being done if it was – if people could do it or an animal could do it to make it easier. If we do a peasant meal and it takes 5 people to pump the water that'd be great. Or, when the time could come we'll just bring the animal over... whether we incorporate that into the peasant meal or the global village overnight or not..."

Woman: "Right. Especially the week-long group... they could see how much easier it is with an animal. Because that is one of the things we talked about: how animals are improving peoples' lives."

Dale: "And certainly if you could pump it without the animal. Even if it took six people to walk and push something – that doesn't bother me. And that would be I think one of the designs ideas – are they pumping water for immediate access or are they pumping water to fill a reservoir or to fill..."

Shaun: "Another thing is: depending on the size of the well and the pump, there might – we noticed that there were trees around the site. Is it out of the question to take down a tree? I know that might kind of against the whole..."

Dale: "No, we're deforesters here."

Shaun: "OK, then."

Dale: "We thought that it would be nice to have the well or the pump under a nice big shady tree, but we realize that that may not be possible. And that's not a problem. We want the well to have a little cleared spot anyway... It'd be fine."

Man: "I'd rather not take down lots of trees if we don't have to."

Shaun: "At the most: 2, i think."

Man: "Tree-hugger."

Group 2

Shaun: "The first question we have: is there anything this well could provide that would be appealing to its audience, that would draw public attention. Is there anything off the top of your heads."

Boy: "If it was fancy and had crazy woodwork."

Girl: "If it was designed in an unusual way. If you made it with old Coke bottles that would be available – made of recycled material."

Boy: "People wouldn't come to see the well unless it was special."

Girl: "If it was made by someone special."

Girl: "If the only way to get water out was to lead a goat around in a circle."

Boy: "Or if you got everyone around here to help. Like if it wasn't just you guys. Then people would come to see it, if the community made it."

Girl: "Wait, what kind of audiences are we trying to draw?"

Shaun: "Anyone that's here."

Girl: "Why would I go look at a well?"

Girl: "If it was hand-dug. I don't think they'd appreciate it. If once the well was created, they had people come in and do shifts that were part of it. Like if you learned how to pour the cement. Because everywhere else you experience the life of being a Tialander."

Girl: "You could put goldfish in it."

Girl: "If there was something special about it that they could then participate in."

Boy: "If you made a... types of getting water up?"

Shaun: "There's lots of types."

Boy: "Isn't there one that comes up and kind of shoots it up like..."

Girl: "A geyser?"

Shaun: "There is one like that but I think..."

Girl: "Yeah, definitely... bucket..."

Boy: "An artesian well."

Girl: "Yeah, a bucket well would be cool. As opposed to one with a pump handle; because that would be funky."

Girl: "Yeah, like a real old fashion well it's got the little brick sides..."

Shaun: "Another thing is: how would you feel if some of the research we gathered – like the statistics – were written on the well, just so people got a rough idea..."

Boy: "Yeah, on all of the bricks and stones."

Girl: "Yeah, on each stone you could have a statistic."

Boy: "And I like to hear percentages more than numbers, because it's hard to think about numbers, but percentages you say – oh wow that's a lot of people..."

Girl: "The only thought with that though is that in ten years – this well is hopefully going to last for a while – in ten years those percentages will hopefully change... is there some way that they could be..."

Shaun: "Updated?"

Girl: "Yeah, because it would be kind of sad if in 2025 you come back and are like, 'That's so wrong.'"

Girl: "You could leave bricks blank and do – I don't know how many bricks or stones or whatever you're going to use for the well – you could do a column for each year and you could write the percentages for each year and go around and – maybe you'd only have 20 columns. You could see how it changes. You'd have a set of bricks and you'd say, 'In Uganda, % of people who don't have access to clean water' or 'number of people who die per minute from lack of clean water'... And then as time progressed people would see, is it improving, is it not improving? And I think that would have a pretty dramatic impact. Because you could look along the line and go, 'Oh my gosh, it's getting worse.'"

Shaun: "The the second main question: is there anything you can think of – or any ways you could think of – in which the public would be involved in the use of the well."

Girl: "That'd be kind of hard to... have the project in the global village. You could make it a lucky-penny well or something."

Girl: "Those are common enough."

Girl: "Not really, not anymore."

Boy: "They have a little 'Make a Wish' well over there and it has a bucket in there... And you could just have one bucket always sitting there..."

Girl: "You can't really change the quality of the water, though. Is there someway to make what you get out special, people would come."

Girl: "OK, why would people come and – what would make them..."

Boy: "Because people like wells. They would just go to it anyway."

Girl: "Unless there's some event going on at Heifer Project, I don't think anyone's going to come just to see the well – no matter have fancy you make it."

Boy: "If it was nationally broadcasted people would come and see it."

Boy: "A well?"

Girl: "Well like the final stone in the well. There's got to be something special that would make them want to broadcast it on national news – or even New England news."

Girl: "Like every penny people throw in there goes towards reducing hunger in a nation or something."

Boy: "No one's going to come to see that."

Girl: "If there's some way people could use it for something. If every Wednesday someone could claim that so many pennies would go to this or that or another thing – we could have a local... You could put in – one day I want all the money to go to starving children in Uganda or Tibet. And each day it would change. But then you wouldn't get enough money anyway. I don't know."

Shaun: "I think one way would be if they pumped it. Do you think – would they like to pump it – assuming it was a pump well – do you think the visitors would like to pump their own?"

Girl: "I think they'd enjoy it more if it was one of the little bucket wells, because those are more old-fashioned – 'Oh I used to use that well, and it was so cool.'"

Girl: "I think Jake was right, that little kids would fall in and drown, and it would be sad."

Girl: "No, you could lower the bucket and haul them out."

Boy: "If you could get someone special from Massachusetts – like if the governor came or something and scooped up the first water... people would be like 'Ooo, I want some water too.'"

Girl: "Yeah, if the governor took a drink of the water or something, as long as it wasn't like..."

Boy: "And get sick."

Shaun: "Another thing is that: there are some wells that are kind of children's toys – like merry-go-grounds and seesaws. What would you think if the well was a seesaw or something like that."

Girl: "Oh that's so cool."

Girl: "That's a good idea."

Girl: "A merry-go-round might be a little silly. But adults can do a seesaw."

Shaun: "The other thing is that – since it's an animal farm – there are some pumps that are powered by animals except..."

Girl: "Like the goat?"

Shaun: "...Right..."

Boy: “You could put a little cage there. You could have to handles – one on one side with a hamster pulling it.”

Shaun: “I don't know if a hamster would be strong enough.”

Girl: “No, on the wheel? I don't think so.”

Shaun: “A lot of the ones that use animals usually use camels and donkeys.”

Girl: “We could use goats.”

Girl: “We could use water buffalo.”

Boy: “A yak.”

Girl: “I think the yak might trample small children.”

Appendix 4 – Slide Show

Heifer Well Project

Shaun Calhoun
Jen Peters
July 22, 2003

Purpose

- to design a community well for the Overlook Farm's global village

The Survey

- A series of 21 questions asking for the subjects' knowledge and opinions of the global water situation
- Most were multiple choice, true/false, and a few open-ended questions

Results

- 43 responses, some incomplete
- majority over age 50
- only 9 were male
- showed that most people know little about the global water situation
- some answers were surprising, while others were not

1. Will America run out of freshwater someday?

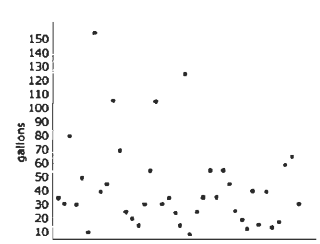
- most answers 'likely' or 'very likely'
- 7 answered 'unlikely'
- 1 (a 12 year old) answered 'very unlikely'

What does this mean?

- most people are aware that our current system is not sustainable
- the 12 year old might be cause for concern since she was the youngest to take the survey

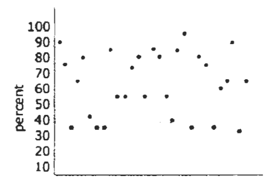
4. The average person living in sub-Saharan Africa uses 2-5 gallons of water per day. How many gallons per day does the average person in North America use?

- correct answer: 100 gallons
- average response: 37.575 gallons
- 2 were correct, 2 overshot



15. What percentage of the human population on Earth does not have access to safe drinking water?

- correct answer: 20-35%
- average: 64.3%
- no one undershot

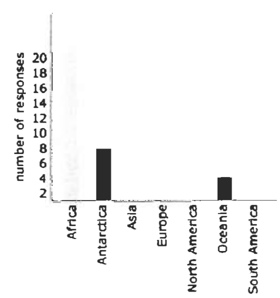


What does this mean?

people do consider water scarcity a global problem

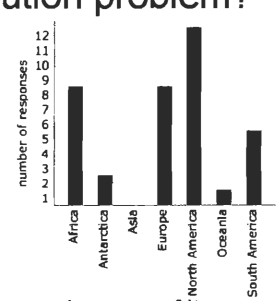
13. Which continent has the worst water scarcity problem?

- answer: Africa
- most people were correct



7. Which continent has the worst water pollution problem?

- answer: Asia, followed by Africa
- most answered North America, followed by Europe and Africa



- However, our answers were in terms of its effect on people. While North America's water bodies are severely polluted, our drinking water is of a higher quality than most places on Earth.

8, 9. How serious is the water pollution problem globally, and in your state (on a 5 point scale)?

- 8. average: 4.4 (globe)
- 9. average: 3.5 (state)
- no one thought their state's problem was worse than the globe's problem
- seems contrary to question 7, which showed that people believe North America has the worst water pollution problem.

Water Pollution

Globe: 4.4 State: 3.5

- less than a 1 point difference (out of 5)

What does this mean?

- people are overestimating the local problem
- they think the global problem isn't much worse than the local problem
- they fail to realize how lucky we are, in comparison to the rest of the world
- if they truly understood how severe the global water pollution problem was, they would have answered 2 or 1 for state

Focus Group Interviews

- 2 groups
- same questions for both groups
- engaged in discussions amongst themselves to answer each question

Question 1

What could the well provide that would be appealing to its audience?

1. Group 1

- "something moving... something they can participate in"
- "they can get water from it"
- "on the tour they could pump water"

1. Group 2

- "if it was designed in an unusual way... made with old soda bottles"
- "made with recycled material"
- "if the only way to get water out was to lead a goat around in a circle"
- showed a fondness toward "bucket wells"

Question 2

How would you feel about a text display showing information about the global water situation?

2. Group 1

- in the end, they concluded that some type of information available would be beneficial, but a sign would go against the visual theme of the global village
- one person suggested a notebook

2. Group 2

- showed no objections to a text display
- one person suggested that the statistics be updated
  - "as time progressed, people would see: is it improving? is it not improving?"

Question 3

How can the audience be involved in the use of the well?

3. Group 1

- important for the audience to relate their experience
- could they drink it? not the well-water
- one person suggested 2 tanks
  - one filled with well-water from the ground
  - one filled with tap water from a hose to drink

3. Group 2

- a "lucky penny well"
- if the pennies thrown in were donated to charity

Question 4

How would you feel about a well in the form of a ride-on toy such as a seesaw or a merry-go-round?

4. Group 1

- reactions were generally negative
- "too fun and commercialized"
- "what message would that be sending?"

4. Group 2

- reactions were positive about a seesaw
- "a merry-go-round might be a little silly"

Question 5

How would you feel about a well that was pumped by animals, instead of people?

5. Group 1

- one person noted that this would fit Heifer's theme
  - "that is one of the things we talk about: how animals are improving peoples' lives"
- important that people also be able to pump it, "even if it took six people"

5. Group 2

- seemed to approve of the idea
- focused more on what type of animal to use
  - "hamster," "goat," "water buffalo," "yak," "guinea pig"

Pump Options

- Volanta Pump
- Afridev Pump
- Horse Rope Pump

Volanta Pump

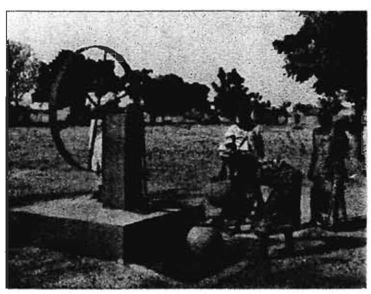
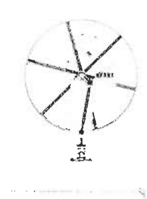
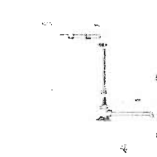


image taken from www.handpump.org

- widely used throughout Africa
  - Mozambique
  - Burkina Faso
  - Niger
  - etc.
- for wells 10 – 100m deep

Volanta Pump : how it works





images from lifewater.ca

- large steel flywheel spun in a circle
- rotary action causes pump rod to move up and down
- vertical pumping action sends water out of the spout

Volanta Pump

Pros

- unique design
- easy to use
- easy to install
- virtually maintenance free
- reliable construction lasts for many years

Cons

- spinning flywheel is a potential hazard
- masonry work required for base

Volanta Pump : cost

- made by only one company
  - Jansen Venneboer (Holland)
- cost excluding shipping and taxes: €1,342 (approx. $1,522)

Afridev Pump

image from lifewater.ca

- widely used throughout Africa and Asia
  - Pakistan
  - Kenya
  - India
  - etc.
- for wells 10 – 45m deep

Afridev Pump : how it works

- lever moved up and down by hand
- with each stroke water is lifted out of the pipe through a spout

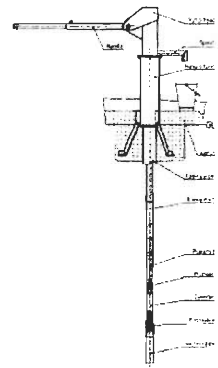


image from www.pat-drill.com/pdf/Water%20Lifting.pdf

Afridev Pump

Pros

- meets all VLOM (Village Level Operation and Maintenance) standards
- easy to use
- easy to install
- reliable

Cons

- some masonry work needed

Afridev Pump : cost

- because of its popularity, there are many suppliers
- cost varies, but is usually less than $1,000

Horse Rope Pump

image from home.planet.nl/~holts000

- the only animal-powered pump produced for sale
- not widely used; mainly in Nicaragua
- for wells up to 70m deep

Horse Rope Pump : how it works

- modification of the Rope Pump
- pulley system raises water via an endless rope with pistons attached
- horizontal gear added to allow power to come from a work animal walking in a circle

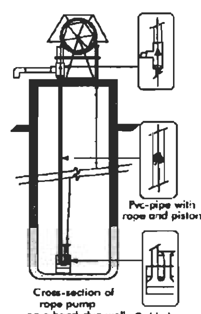


image from www.wsp.org/pdfs/global_ropepump.pdf

Horse Rope Pump

Pros

- fits well with Heifer's theme
- can be powered by any work animal (not just horse) or human
- very little maintenance

Cons

- difficult to install
- not very efficient

Horse Rope Pump : cost

- made by only one company
  - Aerobombas de MECate (AMEC) in Nicaragua
- cost excluding taxes and shipping: approx. $390

Ground/Tap Water Options

- Groundwater
- Tap water
- Both

Groundwater

Pros
- realistic
- impressive

Cons
- unsanitary
- could dry up
- might not be any water

Tap Water

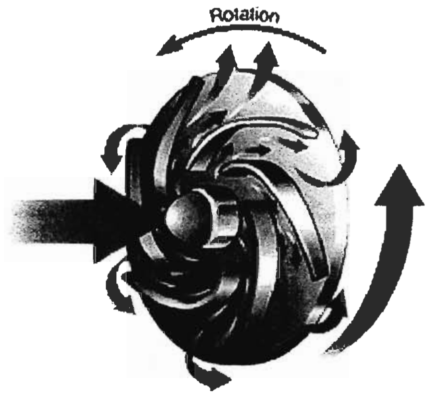
Pros
- sanitary
- reliable water source
- choose the pump's placement
- less digging

Cons
- requires extra hoses, valves, etc.
- may require a water tank

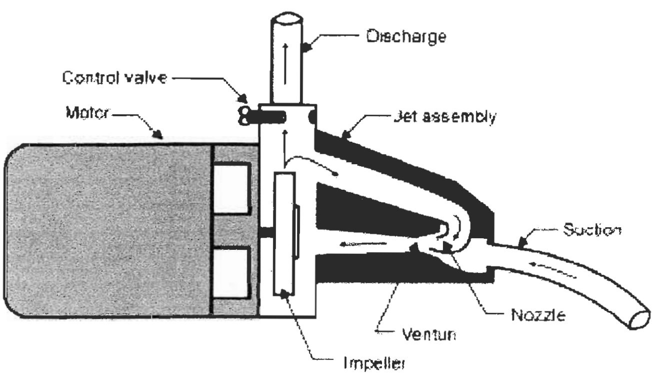
Combination

- many possibilities
- a second pump?
- using only one pump would require at least one water tank, possibly two

Appendix 5 – Pump Photos



Centrifugal Pump
Type: variable displacement
Source: http://www.kraftunitops.com/pump_positive_displacement.html

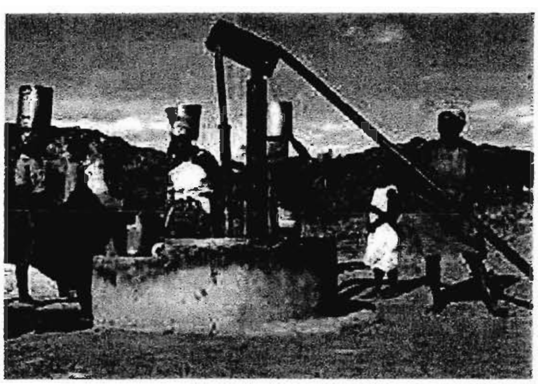


Jet Pump
Type: variable displacement
Source: http://www.agric.gov.ab.ca/images/700/716c12a.gif

Afridev Handpump
Type: positive displacement

Source: http://www.lifewater.ca/afridev.htm

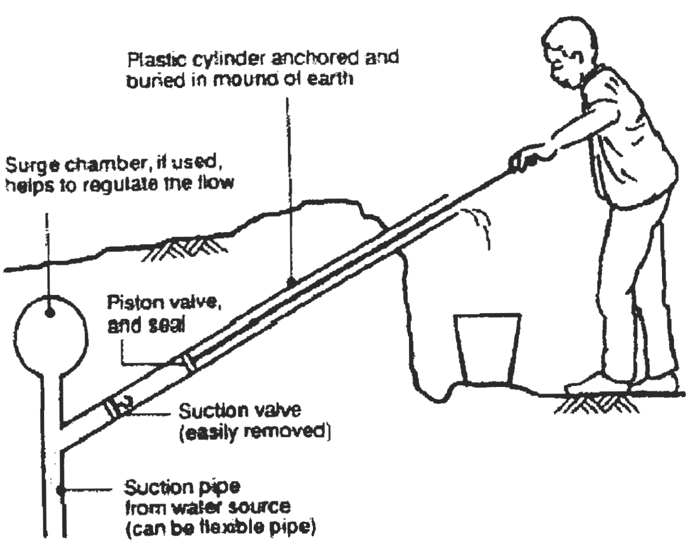
Blair Pump
Type: positive displacement
Source: Developing World Water



Bush Pump
Type: positive displacement
Source: http://www.lifewater.ca/Section_13.htm

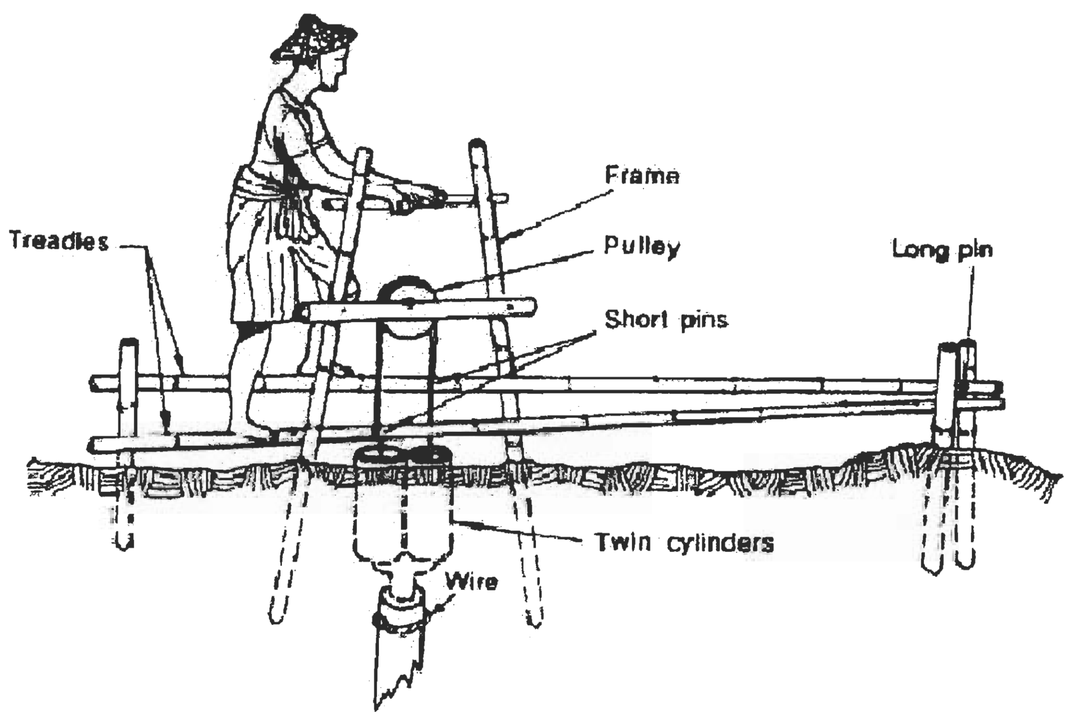
India Mark II
Type: positive displacement
Source: http://www.lifewater.ca/mark2.htm

Kardia Handpump
Type: positive displacement
Source: http://www.lifewater.ca/kardia.htm

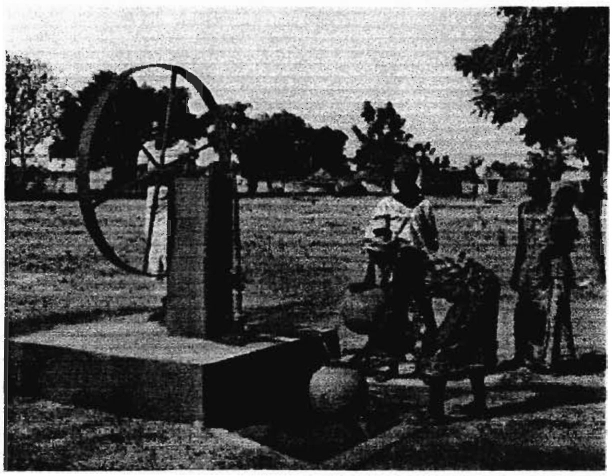


Rower Pump
Type: positive displacement
Source: http://www.itdg.org/html/technical_enquiries/docs/human_water_lifters.pdf

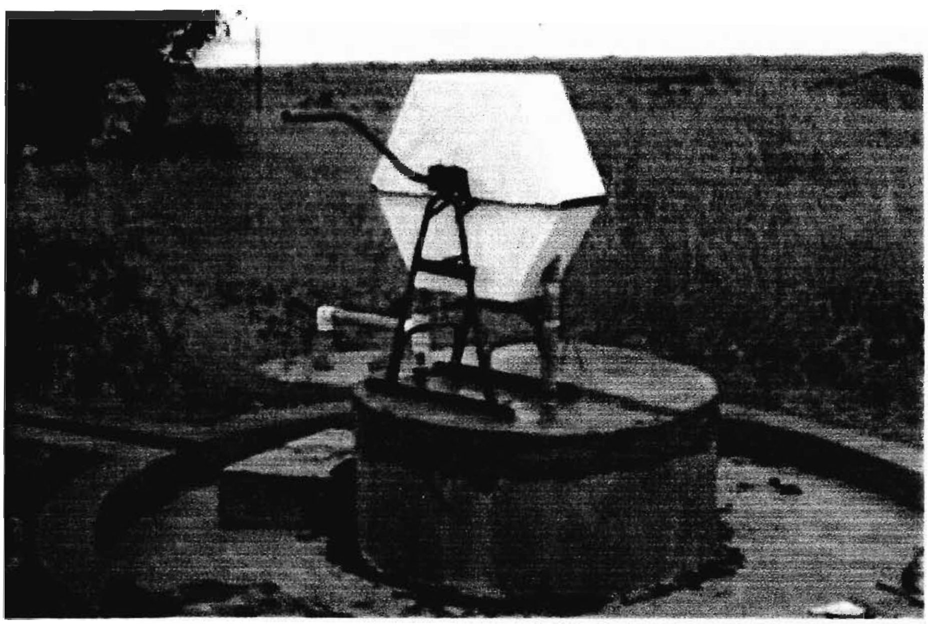
Tara Handpump
Type: positive displacement
Source: Developing World Water



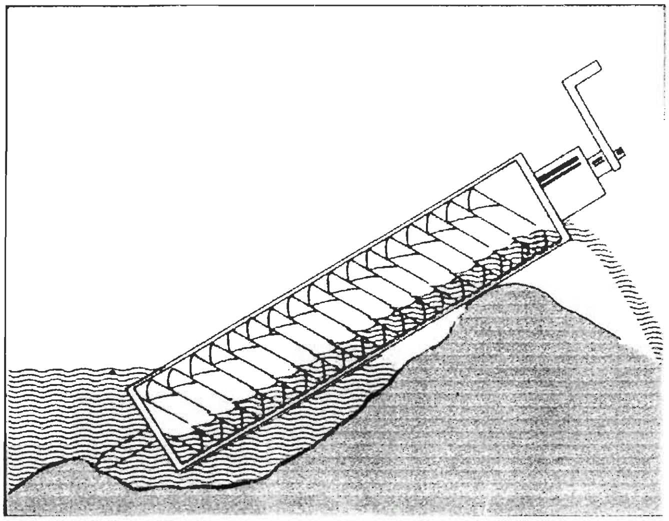
Treadle Pump
Type: positive displacement
Source: http://www.itdg.org/html/technical_enquiries/docs/human_water_lifters.pdf



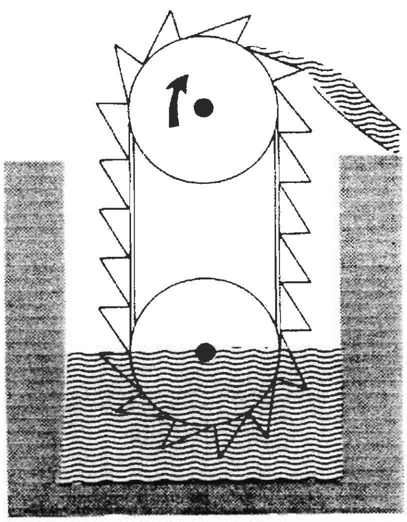
Volanta Pump
Type: positive displacement
Source: http://www.handpump.org/O&M.htm



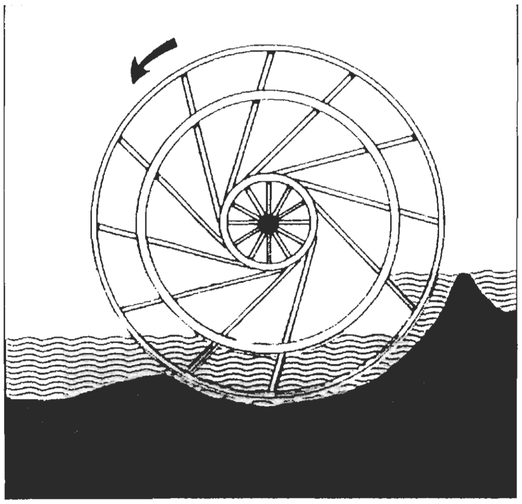
Rope Pump
Type: positive displacement
Source: http://www.ropepump.com



Archimedes Screw
Type: free surface
Source: Developing World Water



Bucket Pump
Type: free surface
Source: Developing World Water



Scoop Wheel
Type: free surface
Source: Developing World Water

Appendix 6 – Heifer Specific Data on the Global Water Situation

	Est. Population	% Access to Safe Drinking Water			% Access to Sanitation		
Country	(millions)	Urban	Rural	Total	Urban	Rural	Total
Thailand	60.5	89	77	80	97	96	96
Peru	25.66	87	51	77	90	40	76
Guatemala	12.22	97	88	92	98	76	85
China	1276.3	94	66	75	68	24	38
Kenya	30.34	87	31	49	96	81	86
Uganda	22.46	72	46	50	96	72	75
Poland	38.73						
Ukraine	50.8						
India	1006.77	92	86	88	73	14	31
United States	277.83	100	100	100	100	100	100

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