Providing Potable Water to Peruvian Informal Settlements

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Executive Summary:

The goal of this project was to provide Manchay, a slum in the Pachacamac District of Lima, Peru, with a sustainable source of fresh and potable water via technology that is independent of government-based water sources that can be applied to other slums and communities that experience similar water issues. In order to achieve this goal, we had three objectives to guide us:

1. Identify different technologies that could provide potable water to our region of focus.
2. Evaluate potential technologies on different criteria, including economic feasibility, environmental friendliness, cultural acceptance, longevity, as well as numerous other factors we deem as important.
3. Determine a fair distribution plan for the gathered water for the region of focus.

The overarching issue in Manchay is the lack of potable caused by distributive injustice from private water companies, political corruption and negligence from the Peruvian government, and widespread poverty in the informal settlements of Peru. As a result of the lack of potable water, there exists the purchasing of expensive private water, poor water quality and living conditions, and a daily water per capita amount that is below human rights standards.

To tackle the problem, we researched different technologies that might alleviate the lack of potable water, Manchay's culture, social norms, and economic status, and a fair way to distribute water. First we read articles on the entirety of Peru and informal settlements, while also exploring river filtration systems and atmospheric water generators. Then, we conducted interviews with Professor J. S. Jiusto, Professor R. C. Peet, and a researcher in Manchay named Tony Callery. Next, we designed a decision matrix to assess the different technologies that we researched.

As we examined our technologies, we weren't satisfied with any one technology, so we decided to combine certain atmospheric water generators into one.We combined a base atmospheric water generator with 4 mono-crystalline silicon PV panels, a electrostatic membrane, and an underground constructed condenser to minimize energy costs and produce more water for the desired target people group. We estimated that our machine could produce around 2500 gallons per day running entirely on solar power. In other terms, we could give 500 people around 20L each.

While we were busy designing our hybrid atmospheric water generator, we developed an implementation plan to put our technology into place. By partnering with UTEC, a Peruvian university of technology and engineering, and the local church in Manchay, we would produce the technology and place it in on top of the hill in Manchay to provide potable water to the people. When partnering with the local church, our WPI team would work to create a fair distribution plan that is fair to the people of Manchay, not necessarily fair by American standards.

Once the technology has been established, recognized, advertised, and guarded by the church, students from UTEC would come to Manchay to take statistics on the success of the technology. By analyzing the machine's output and energy usage and conducting surveys on the major leaders and people affected, we would be able to make a decision whether our atmospheric water generator should be implemented in other locations around Peru and the globe. If the surveys show consistent data from the technology and positive feedback from the community, then we would partner with more local areas to give them their right to water.

Introduction:

In our project, we analyzed the water problems in Manchay, a slum in the Pachacamac District of Lima, Peru, in order to try to find a solution. Our goal was to provide them with a sustainable source of fresh and potable water via technology that is independent of government-based water sources that can be applied to other slums and communities that experience similar water issues. In order to achieve this goal, we had three objectives to help guide us:

1. Identify different technologies that could provide potable water to our region of focus.
2. Evaluate potential technologies on different criteria, including economic feasibility, environmental friendliness, cultural acceptance, longevity, as well as numerous other factors we deem as important.
3. Determine a fair distribution plan for the gathered water for the region of focus.

The reasons why this slum is not being given a sufficient amount of affordable public water include the fact that the water trucks are not giving them enough, as well as the government being unwilling to help solve this problem. To begin with, Manchay is located on a hill, with most of the wealthy people living at the bottom and the poorer ones living at the top. Water trucks are able to go to the bottom every day, while only serving the top once or twice a week, and so this creates distributive injustice. This also negatively impacts the poor, as they have to pay more for their water than the rich due to how scarce it is. We interviewed a man named Tony Callery who lived in Manchay and he said "Peru is a desert and water is gold," and this exemplifies how much they are in need of a potable water source. Our project seeks to focus on the top of the hill and help them have more access to potable water. Next, the government is another factor in Manchay's water problems. They refuse to identify them as cities and categorize them as informal settlements, and so do not want to improve the infrastructure in order to provide affordable public water. This problem caught our attention because we believe it is unfair the way this slum, amongst many others, is being treated, and we want to fulfill a human's right to water.

After analyzing many different technologies, we decided on using an atmospheric water generator over a river intake filtration system. However, we also looked into several different types of atmospheric water generators that each use different technologies. In our design, we hope to combine three aspects into one cost and energy efficient technology; these aspects are solar power, electrostatic membranes, and the underground condensing power of the waterseer. We think this solution will address the problem because it will take something that is abundant in Peru, humidity, and turn it into water. We expect this atmospheric water generator to provide around 2500 gallons of water per day, enough for about 500 people.

Literature Review:

Introduction

How easy is it to access water? Perhaps it is filling up a cup in the sink, or even a walk down the hall to the closest water fountain. Living in a developed and modernized country, we are often oblivious to the issues which surround water in the world around us. An astonishing 1.1

billion people worldwide lack the resources and materials to access clean drinking water, and resort to unsafe water sources (Sobsey, 2008). Water scarcity can be defined as the lack of sufficient water resources to meet the needs of the people within a community, country or region. In our team's case, we are targeting on a specific aspect of water scarcity. We will investigate the lack of clean drinking water in the slums also known as *barriadas* or *pueblos jovenes* in Manchay, Pachacamac, Lima, Peru. Those in the slums consist of people who cannot access the amount of clean water which is necessary to live in a safe environment.

The slums represent the surrounding area of Lima where poverty prevents people from easily accessing clean drinking water, modernizing sanitation, infrastructure, housing, water systems and other technical resources that are necessary to a community. People living in Peruvian slums, such as the San Juan slums, experience a lack of drinking water which can be attributed to its lack of infrastructure for drinking water, distributive injustice, poverty, and environmental concerns. There are a variety of causes that contribute to the lack of clean drinking water in Lima Peru.

Causes

Infrastructure

In the 1950s, Peru saw a massive amount of immigrants pour into the country. From 1948-1956, thousands of houses were built in Lima, but they could not accommodate the 30,000-50,000 new immigrants arriving each year (Ioris, 2012). As a result of the lack of housing, many immigrants created squatter settlements without urban services known as *barriadas* around the city of Lima. With the growing number of immigrants, slow production of suitable housing, and increase in *barriadas*, the government eventually accepted the *barriadas* as a section of the city to be supported and legalized. In 1995, the *barriadas* held 10% of Lima's population, in 1970, they held 25%, and in 2002, they held 35% (Riofrio, 2002).

Being squatter settlements, the *barriadas'* immigrant inhabitants build their own shelters out of woven reed mats, plywood, or cement. Only later may the government give the inhabitants title and basic services. Even though the people may receive title, they are represented by only one real estate intermediary who may or may not support his people. If an area is under a corrupt intermediary, an area may not get adequate resources. In most *barriadas*, the neighborhoods give the inhabitants an opportunity to insert services such as a clean drinking water source. But without the money to establish the services, families living in the *barriadas* may not be able to receive drinkable water in their shacks (Riofrio, 2002). If a family does not have a water pipeline, potentially susceptible to bacteria, a family may buy water from expensive private water sources (Ioris, 2012). Depending on the *barriada*, around 50%-75% of people have a public water source, while the rest of the inhabitants rely on private water tankers.

Political

The lack of infrastructure and clean drinkable water in the *barriadas* can be contributed to the political situation in Lima, Peru. In 1962, the government designated SEDAPAL as the main public utility for Lima, Peru. SEDAPAL had wasteful practices and poor sanitation, but the government used them anyway. In 1980, 20% of the population still bought from private vendors. Of those that used SEDAPAL, 40.6% did not have reliable water, and 50% of the treated water was wasted due to leakage. In 1991, after an outbreak of cholera in Lima, the Fujimori administration wanted to privatize SEDAPAL to supposedly combat the outbreak with a major competitive water company. Even though the government gathered money from taxes and agencies for the privatization of SEDAPAL, the government cancelled its plans to privatize SEDAPAL due to a supposed lack of money. With the excess money gathered, the government invested into providing high income areas with adequate water, while in turn the government gave less water to the low income areas, more specifically the *barriadas*. The privatization plan may have been simply a political false promise for the Fujimori administration to gain more votes (Ioris, 2012).

In 2007, a new administration under Alan Garcia launched an initiative to provide "Water for All." Even though the multi-billion dollar project fixed some aspects of SEDAPAL, households in the *barriadas* still continue to have either minimal clean water or no water at all to this day. In 2001, at least 157,000 families in Lima mainly in the slums did not have access to water. Even with water services, that water may only service treated water for a few hours of the day (Ioris, 2012).

As a result of the historic corruption and negative association with SEDAPAL, the people of the *barriadas* are hesitant to accept new technologies from SEDAPAL. In 2005, SEDAPAL tried to introduce a low-cost, sanitation technology, but the people rejected the offer because they thought the technology was a second-rate plan for the poor. When honest improvements are presented, the strong distrust between the people and government may prove to be a further obstacle for safe drinking water in the years to come (Ioris, 2012).

Environmental Concerns

Peru's capital, Lima is built on the Sechura Desert; which only receives about 25 mm of rainfall annually (Ioris, 2012). Not only does it receive virtually no rainfall, Lima is also located on the West side of the Andes Mountains; this region has about 2% of the country's water and harbors about 70% of the population (Painter, 2007). As a result, the slums heavily rely on the glacial melt in the Andes mountains for a source of clean fresh water.

Glaciers naturally collect and hold snowfall during cold months and then slowly release some of this moisture during the warmer seasons. This may seem like an effective and reliable source of water considering Peru is home to Cordillera Blanca, the largest tropical glacier train in the world. However, increased temperatures and humidity in the Andes quicken the pace of glacial melt. This may be useful in the short term, but in the long run, the conditions affect the size of a glacier. Over the last 50 years, Cordillera Blanca has shrunk 15% and if it (and other glaciers) continues on this trend it could potentially dry out rivers as a result of having no glacial melt (Lubovich, 2007). If glacial melt stops providing large amounts of clean freshwater to the slums in Lima, then the people living in these slums will suffer greatly. They will lose one of their largest sources of clean drinkable water that can also be used in the agriculture and mining industries.

Poverty

Looking at Peru from a broader perspective, the major industries of Peru are agriculture and mining, both of which require an immense amount of water while creating a lot of jobs for Peruvians, some of which live in slums. Peru's agricultural industry accounts for 82% of Peru's water consumption, but currently only 8% of farmlands use water efficient technologies like drip irrigation (Fraser, 2009). The nature of these industries is to use water but not to put any clean water back into the environment.

Since these industries consume so much water without producing clean water, there are fewer sources of clean drinking water for the people living in the slums. Although these large industries produce a lot of job opportunities for Peruvians living in slums, ⅓ of Peruvians make less than $2 a day (Lubovich, 2007). Low income amongst the people in these slums around $3 or more for 2 days-worth of clean water (a 100L tank of clean water from a private vendor). Peru already has a 10% unemployment rate, but with the rapid melting of the Andean glaciers, more Peruvians are expected to become unemployed (Lubovich, 2007). If this unemployment rate increases, the situation will be even more difficult for Peruvians living in slums to afford the high price of clean drinkable water. We will explore more of the impacts of the above causes in the next section.

Impacts

Families

When looking at the large percentage of poverty in Lima and the high price of water, it is no surprise that people living there have many issues acquiring and using their water. The sparse amount of water that these families do acquire must be used for all household necessities including cooking, cleaning, drinking, and bathing. Because of this, many families take extreme caution by rationing their water. Additionally, there is heavy speculation about the cleanliness of the water from the different mediums that the people retrieve it from. In 1995, 25% of Lima did not have access to clean drinking water (Lubovich, 2007). When you are drinking the same water you bathe in, wash your dirty clothes in, and clean your home with, it is no surprise that many people are not drinking clean and safe water. In 1991, the cholera outbreak referred to in an earlier section occurred in Lima due to “inadequate public health infrastructure and microbial contamination of water supplies” (Ioris, 2012). Peru has had a history of unclean drinking water which continues to lead to serious health complications.

Health

In communities such as the *barriadas* in Lima, contamination of common tap water is an ever-growing issue. Not only do these neighborhoods suffer from unclean drinking water, but they also tend to practice poor hygiene and water storage methods which lead to further health complications. In these slums, health issues such as diarrhea, infant death, and countless other diseases and infections can occur due to the poor practices of its people. In Lima, the infant mortality rate is 26%, one of the highest in the world (Gonsalves, 2011). Furthermore, there is an exponentially increasing problem with fecal contamination within the water systems of these slums and throughout Lima. A study conducted on the fecal matter found within the drinking water of the people living within Lima states that, "data suggest strongly that the major sources of contamination resulted from poor water storage and hygiene practices in the home" (Oswald, Lescano, Bern, Calderon, Cabrera, Gilman, 2007). Here, it is evident that the practices of these people contribute to the unclean nature of the water they drink. Finally, we can see that diarrheal disease is a leading cause of death among children in the city of Lima and across Peru. These deaths can be linked to the unsafe drinking water and to the lack of drinking water that is available to most families who are living in poverty. Aside from the health issues, there are drastic economic consequences that come with this ever-growing water scarcity in Lima.

Economics

In a country where 10% of its citizens are already unemployed, going to school and working are essential in order to live a comfortable life. However, due to the lack of drinking water in the *barriadas*, households are forced to sacrifice time for collecting water, which in turn restricts them from using this time for either school or work. According to Arlene, a student at American University who visited the slums of Peru, "thousands of children do not attend school past elementary because of the need to help provide for their families" (Arlene, 2013) Furthermore, if children get sick from a waterborne illness, then they cannot go to school, and their parents are forced to stay home and take care of them, thus prohibiting them from going to work. Moreover, some adults, especially women, do not have the ability to get a job and make income because of the need for water, and so they continue to live in poor conditions. As a result, many families in the slums do not have the funds to buy an adequate amount of clean drinking water.

Conclusion

Due to the corruption in the Peruvian government, wide spread poverty, expensive private water sources, social distrust, and a depleting source of water, the lack of potable water crisis in Peru continues to spiral out of control. As a result, the people grow into more poverty, are at risk of health issues, and cannot take control of their lives. To combat the lack of potable water in specifically Manchay within Lima, Peru, we plan to approach the issue through a three step process: analysis, design, and presentation. In the analysis step, the group will research for an innovative, economically feasible, politically and socially friendly technical solution that will treat the lack of potable water in Lima's slums. Atmospheric water generators and river filtration systems may help to produce potable water. Since any solution requires social acceptance and usage, proper design is key to successfully later implement the solution. In the design stage, the team hopes to focus on one technology through use of an extensive criteria and create a sustainable plan to implement the technology. The team believes that the solution will require maintenance and improvement over time to remain effective. The team will formulate an accountability system that will prolong the use of the solution and ensure equality to the targeted region. In our final step, the presentation phase, the team seeks to communicate its plan to organizations who intend to solve this issue in Peru. Every day, less and less water is available, and more and more people are suffering in Peru. The injustice in Lima is real and supported by powerful political figures and private companies, yet with modern technology, proper implementation, and political accountability, we believe that a solution may be formed to break through the discriminatory barriers that oppress the *barriadas* of Lima, Peru.

<u>Methods:</u>

Objective 1 - Identify different technologies that could provide potable water to our region of focus.

To begin our research, we first had to look at and get an understanding of the possible technologies that are available to us. We chose this for our first objective because it allows us to look into several technologies so that we can analyze them all and assess which one is the best solution to our problem. In order to carry out this method, we had to start with the process of collecting data. We collected the majority of this data through the use of secondary sources; we used peer reviewed and other reliable articles found online to aide in data collection. We also had interviews with professors, people involved in the water industry, and informal conversations with our professors in class to gather data and research ideas for our technologies. When collecting data, we had four key objectives in mind during our research: determine the cost, efficiency (water output), power input (wattage), and long-term benefits and drawbacks of each technology. We would later compare and contrast the figures for each technology against each other to find which one is the most viable for our needs.

Objective 2 - Evaluate potential technologies on different criteria, including economic feasibility, environmental friendliness, cultural acceptance, longevity, as well as numerous other factors we deem as important.

This was an important objective to fulfill because we had to determine which technologies were going to be feasible for our area. There are many dimensions that are present when working in an unfamiliar area, so we had to develop a greater understanding of the culture and landscape of our area, and the possible restrictions that may be presented to us with those dimensions. We found this information through the use of secondary sources found online (that were either peer reviewed or determined reliable). We also gathered information through interviews with professors who dealt with the International Qualifying Projects at WPI as well as people familiar with the culture of Manchay. When collecting data, we determined that we would focus on three sub-objectives during our research for this objective: find information on cultural values, find information on the maintenance costs and longevity of the systems in correspondence with those values, and determine figures on cost and production of different technologies. We would then use those figures and the information found on our area to determine two things: how we would monitor the project (employ someone) and what our desired price-range would be for our area.

Objective 3 - Determine a fair distribution plan for the gathered water for the region of focus.

This was a necessary objective because we needed to provide a solution that implemented distributive justice and equity. The proper plan for this objective would ensure that the project would be useful for years to come without conflict and extra costs. In order for the people of the area to feel a community sense of ownership, a fair plan of distribution was necessary for implementation. In order to determine what really was fair in the eyes of the people, we had to do an extensive amount of research on the many cultural values of this area. We collected this data through the use of reliable secondary sources and interviews with people who know the area well. We collected data on a number of things: demography (age groups, major jobs, genders, natural rate of increase, disease rate), social norms (uses for water, communication), leadership structure, local income compared to tech costs, and crime rate (possibility of destruction of technology). After the data was collected we created a plan that we believed to be fair for the people of this area using this data and the data from objective 2.

Data and Solution Analysis

In order to determine which solution is the most viable for Manchay as well as recommend how to implement our solution we did a few things. First, we researched Lima's climate and the capacity and usage of the Lurin River to understand the potential water sources we worked with. After that last step, we interviewed professionals that worked with the technologies to determine the most important parts of the technologies to further research them. Lastly, we designed a decision matrix to compare total cost of implementing the two technologies, maintenance costs, and operating cost to determine which technology will produce the most water for the lowest cost.

Design Matrix

Criteria

To further analyze the data that we gathered, we had to create a design matrix to allow us to compare and contrast the data we find for the individual technologies we researched. Primarily, we evaluated construction and implementation cost and compared that to the affordability of the region we worked with. We then compared the efficiency of each solution; more specifically, the amount of water each produced, whether or not the solutions would be worth-while investments, and what the water would be used for. Next, we asked questions about how long each technologies are expected to last, what issues may occur in each system, how much it will cost to fix these issues, and who will fix them? Lastly, we analyzed the sustainability of each system further; we asked whether or not they will be environmentally friendly, and whether or not our system will make a lasting impact on the community around it. So in the end we had to analyze four key components: cost, efficiency, maintenance, and sustainability.

Weight

In order to assess the information that we gathered during research further, we assigned importance values to each of our four criteria for the plans and technologies to allow us to determine how important the benefits and drawbacks of each system were to us; and more importantly, the people of Manchay.

One of the most important factors to us was the cost of each solution. We were very concerned with the price of the technology because of the low-income of the people in Manchay. In order for this area to receive affordable, potable water, the group requires the technology to be a cheaper and safer option than the privatized water they have right now. That is why we determined that the weight of the cost of the system would be **30%** of the criteria considered.

The next factor that we deemed to be high priority was the efficiency of each system. We thought that the technology should be able to produce enough potable water to provide for the people’s needs. If the technology did not provide the amount of water desired, we would be forced to lessen the amount of people we would be helping; and that would not be optimal. That is why we determined that the weight of the efficiency of the system would be **30%** of the criteria considered.

The next factor we considered was the maintenance required for each system. We hoped to implement a solution that will remain in the community for a long time, until a better solution arises. When a problem inevitably occurs such as weather, violence, vandalism, etc, the group desires to have a plan to fix those issues in an affordable, socially acceptable, and effective way. That is why we gave the maintenance requirements of the system **25%** of the weight when evaluating the criteria.

The last factor that we considered was the sustainability of each system. The group wanted to create a solution that minimized its environmental footprint, was long lasting, was accepted by the people, and was free of government help. That is why we thought sustainability of the system should hold **15%** of the weight when evaluating the criteria.

Rating

In order to come to a final decision, each solution was compared to the criteria previously stated in the design matrix and weight section. For coast, we rated the systems by comparing the technology's initial construction and implementation cost to the amount of money the area currently has. For efficiency, we rated the systems by comparing the amount each of them produced (Liters) every day. For maintenance, we rated the systems by using qualitative data on the availability of a person or group that will be conducting maintenance on the system; and, quantitative data on the price of replacement parts and frequency of maintenance. For sustainability, we rated the amount of power from the technology that would not be created by sustainable sources; and, we used qualitative data on the social and cultural acceptability of the technology by the people.

Preset and Emergent Codes

Before the team conducted our formal research, we had preset topics that we expected to show up in our research. Those preset topics included disease, high infant mortality, poverty, privatized water, political corruption, desalination, Peruvian culture, and non-governmental organizations. Much of these topics came from our background research on Peruvian informal settlements in general.

As we took formal data, topics started to emerge that we hadn't thought about before. Emergent topics included Peruvian UTEC billboard, atmospheric water generator, distributive injustice, church influence on Manchay, lack of electricity, solar power, cultural acceptance, crime, Manchay's hill, and fair distribution. As we dove deeper into Peru's slums and focused on Manchay, Peru for it's low public water distribution and high privatized water distribution, we saw more of the real issues that the local people face. For example, Manchay's hill in association with privatized water companies contribute heavily to the lack of potable water on top of Manchay's main hill. Those at the top of the hill don't receive as much water, and that information led us to build our solution around certain injustice events that feed into the overall lack of potable water.

Results:

Objective 1 - Identify different technologies that could provide potable water to our region of focus.

A River Treatment Facility in manchay would produce 100L per person per day which is a huge improvement over 10L of water per person per day and this would come at a fraction of the price they currently pay for their 10L of water. This River Treatment plant would be able to produce up to 2.5 Million Gallons per Day (MGD) by pulling from the Lurin River. The Lurin River is heavily polluted but is still useable and would be much cheaper to treat than water from the ocean (Glickhouse, 2013). The major technologies featured in this 2.5 MGD treatment facility would include a rapid gravity sand filtration system to remove all dirt, sand, and debris, a UV system to kill off any harmful bacteria in the water, and finally the addition of chlorine for distribution and piping (Callery, 2016). Piping for this River Treatment Facility would be much shorter than piping needed for something like a desalination plant because Manchay is located much closer to the Lurin River than it is to the Ocean. The piping should also be as short as possible to limit the distribution points since Manchay is an area with high crime rates. A 2.5 MGD treatment facility would cost about $2.8M with clarification and peak flow considerations, less than $500k a year for maintenance, and less than $3 to treat 1,000 Gallons of water (Callery, 2016). We do not have exact numbers on the wattage needed to power a treatment facility like this but it would likely use fossil fuels to produce the needed amount of energy. Something to keep in mind is that Peru is a desert and water is gold. "The 'social clubs' (political and criminal organizations) will want to take over the distribution to control the local populace but don't let them" (Callery, 2016).

While a River Treatment Facility does produce a vast amount of water, the infrastructural costs and size of the plant lead us to a more sustainable solution: Atmospheric Water Generators (AWGs). By a general definition, AWGs are machines that generate water from the moisture in the air. In Manchay, the weather is optimal for the technology as a whole.

Even though AWGs perform the same task, many are built differently and use different components such as a solar panel or utilize the ground to produce water. As a result, AWGs come in a wide array of costs, efficiencies, energy sources, and sizes. We have looked at 14+ AWGs and the table below shows the data for each type.

Different systems	Initial Price	Energy usage (W/Day)	Production of water (Gallons per 24 hours)	Special Features/ Maintanance
DewPointe DH9	$599	450-500W	3	n/a
Air Water Maker E-10	$2,698	405W	0.5-6 depending on humidity	Can heat water using 500 Watts and cool it using 125 Watts
Dophin 2/ Dragonfly M18	n/a	523-635W	0.12	Counter-size machine
EcoloBlue 28	$1,999	1000-1150W	7	Can heat water using 500 Watts and cool it using

				500 Watts
Watermill	$1,299	300W	3	Uses outdoor air, company is working on using solar tech as well
WaterMaster C2000	n/a	750W	6	Can heat and cool water using 1250 watts, uses Crystallisation instead of condensation to collect water
AquaMaker AM10	$1799	650W 500W for heating	2-10	Hot water, has enclosed pack filtration system
Skywater (Pontious, 2016)	> $3500	264000W	300	Large output and commercial
Gr8 Water (Pontious, 2016)	> $3500	187000W	3000	Large output and commercial
1 Meter Squared Solar Power Combined with AWG (Kabeel, 2014)	n/a	Solar Powered, but not specified	25	Solar Panel and Condenser Combined, Unlimited Shelf Life, Sustainable

Peruvian Billboard (Peckham, 2013)	$1200	Takes some electricity, but not specified	28	Uses advertisement to fund itself and provide people with water
AWG in San Antonio (Fraade, 2015)	n/a	Use a lot of electricity, but not specified	2000-3000	Large output

We found most of our information either from the distributors of AWGs or from secondary sources that reviewed the technologies. We were impressed by the AWG that combined solar power and an energy storing chemical called brine to create a decent water output. The concept of this AWG lead us to think that we could combine many different elements of AWGs in order to produce a more efficient one that is practical for the people of Peru. In the table below we have listed out the different AWGs that we believe can be combined into one AWG.

Component	Initial Cost ($)	Energy Usage (W/day)	Production of Water (gal/day)	Special Features/ Maintenance
Membrane (Bergmair, 2014)	n/a	107700	4755	produces more water than other AWGs with less power
WaterSeer (Antonio, 2016)	134, but filter may be costly in the long run	No power input required, uses underground water condenser	11	Relatively cheap

		tank that takes advantage of cooler temperature below ground to condense water		
Konstantin Avdienko’s Solar Powered AWG (SunlineEnergy, 2015)	$220	Solar Powered Specific details unavailable; Less sun = less water	.3	Uses solar panel and is relatively cheap

We saw how each of the these AWGs had different costs, energy usage, and water production. But these three AWGs each contained a component that we saw we could use. In a study with the electrostatic membrane AWG, the units with membranes were almost completely independent of atmospheric temperature in the region and produced significantly more amounts of water than non-membrane units (Bergmair, 2014). We knew that we could use the membrane and lower energy cost as well as produce much more water than before. At optimal conditions, the AWG could demand only 63 kW. In the WaterSeer, we see how cheap the device is with almost no outside energy usage with a small amount of water produced. Since the underground condenser cut energy costs because of the natural lower temperature of the ground, we knew we could add the component to our AWG to lower our energy costs (Antonio, 2016). In Konstantin Avdienko’s Solar Powered AWG, we saw the power of solar panels. Even though the machine did not produce much water, the machine ran entirely on sunlight. We didn’t want to use Avdienko’s design but we want to implement solar panels to create a sustainable technology for the people of Manchay (SunlineEnergy, 2015).

To estimate the initial costs, water production, and energy usage of our hybrid AWG, we looked at base components and estimated their costs based on the base AWG's stats on each technology. We based our main AWG frame off of the membrane assisted model. We looked at the low statistics of each technology and the higher end of the technology and doubled or tripled the cost due to our larger AWG to accommodate the solar panels. For water production, we estimated low. For energy usage, we estimated high to make sure that our solar panels could accommodate a flux in the energy usage of the membrane assisted AWG.

Technology	**Initial Cost ($)**	**Water Production (gal/day)**	**Energy Usage (kW/day)**
Membrane Assisted (Bergmair, 2014)	15,000.00-20,000.00	2500-4755	63-107.7
4 Mono-Crystalline Silicon PV Panels (Milani, 2014)	800.00-1,500.00	0	-115
Construction Underground Condenser (Antonio, 2016)	400.00-1,000.00	0-11	0

Objective 2 - Evaluate potential technologies on different criteria, including economic feasibility, environmental friendliness, cultural acceptance, longevity, as well as numerous other factors we deem as important.

By evaluating the condition of the people and the environment in Manchay, we are able to evaluate the technologies. Here is our research on the condition of Manchay.

One of the first things that gets built in these communities is a church and second is a rudimentary school run by the nuns (Callery, 2016). Everyone in the community respects their church and the local Padre, so if you become friends with the local Padre when you first come into town he'll help you and protect you. This is important factor as the church is the community center and note that education is not mandatory in Peru. The father of the family decides whether sons got to work or to school. Crime is a big problem in Manchay which is likely a result of minimal education. If you're living in Manchay, you will get mugged, and depending on how well you protect yourself under the first few attacks you will either always be a target or people will know not to mess with you (Callery, 2016).

In order for a technology to be successful, the technology must produce at least 20L of water to meet the World Health Organization standards. In Manchay, there is also a large economic gap between the poor and rich. The poor pay around $3.22 for 264 gallons, while the rich pay about $0.45 for the same amount. Our technology wants to bridge this gap and provide the poor with necessary water without also overcharging the people.

Since the majority of the people living in Manchay, especially the people living towards the top of the mountain, live in poverty, any of these projects would require a private investor. The cost of any of these water producing machines would be way too expensive for a single family to buy for their personal use. It will be up to the private investor as to whether or not their goal is to make their money back on their investment/make a profit. There will still be opportunities to charge the people of Manchay to take water from this system but it will be cheaper than purchasing it from the water tanks being trucked in.

A River Treatment Facility will first be built using hired workers or even some locals. The benefit of having some locals helping with construction will be that they will feel like it's theirs and they will be more likely to use it. Once it's built, the River Treatment Facility will require less than $500k yearly maintenance which would be completed hired workers who know exactly what they are doing. This River Treatment system would be a longterm solution to Manchay's water scarcity problem. It will be dependant on the Lurin River's water supply but it will be in the area for many years.

Atmospheric water generators contain an outlet for environmental friendliness, especially using solar panels as a source of power. If a solar panel is implemented correctly, there will be no environmental negative impacts. Moreover, atmospheric water generators can be implemented into the informal settlements fairly easily because of their size. The machines can be placed into a room with exposure to the outdoors and generate water. We will evaluate cultural acceptance of the technology by analyzing the above information and create a hypothetical pitch to the padre of Manchay. By highlighting the lower costs, power to the people, and the promise of more greenery, the padres may accept our technology. We do not currently have a plan to maintain the technology because we are still researching the different components of the machine.

Objective 3 - Determine a fair distribution plan for the gathered water for the region of focus.

According to Callery, we are advised to start a collective that is in charge of the water. Locals will be familiar with the concept since the area is agricultural and the definition of fair is culturally subjective (Peet, 2016). We will need a local EPC to make any headway with permits and easements. Also, we need a location for distribution. Since the area can be extremely dangerous and the best way to avoid the violence is through the local padre, we plan to distribute through the local church. To do this, we need to present the idea to the padre and convince him that the technology will benefit the people and give control of the water back to the people. One way we could accomplish this is to show how these machines could allow for vegetation and greenery (Dreifuss-Serrano, 2015). We understand that the people of Manchay respect greenery, and we could offer the potential for plant life an incentive to the local church leaders. Even though the complexity of the machine does not allow for regular people to operate the machine, we can train a local leader how to operate the AWG. Also according to Professor Peet, we may want to use a point system to provide structure and organization to the people. The point system, however, may be ineffective due to the family structure and informal culture of the barriadas. Essentially, we want to convince local leaders to use the technology and work with them to provide the minimum 20L per person at an affordable price that is more fair than the current system. We will charge as close to being free as possible, but leave the end goal to the padre. We have suggestions like the card system, but the decision will be the people's.

<u>Recommendations, Implementation, and Assessment:</u>

Recommendations

My team recommends that we install an atmospheric water generator that utilizes different components of other AWGs to alleviate the lack of potable water in Manchay, Peru and bring distributive justice to the local people. During our research on different AWGs, we saw how different AWGs excelled in different aspects. Some AWGs produced more water than others, while another AWG used considerably less energy. As a result, we came up with an AWG design with 3 components (as seen above in the components analysis). Since there is a lack of electricity in informal settlements, we recommend incorporating solar panels to power the machine. With the help of a solar cell, the machine will be able to store solar energy and produce at night as well as during the day. We recommend adding an electrostatic membrane to the AWG. The membrane filters pollutants in the air but is unlike normal air filters that need to be changed every few months. Electrostatic membranes only need to be replaced every two years and cut down the amount of energy used by the machine. Also, because the membrane only takes in pure air, the machines with a membrane produce more water than those without. We also recommend building an underground condenser within the technology to save energy. Typically, the condenser of an AWG takes up the most energy. By using the natural low temperatures of the ground, we can cut down on the amount of energy used. All three components work together to make a more efficient, less energy consuming sustainable solution. We recommend to place the AWG at the top of the hill in Manchay to accommodate the poorest region of Manchay. In Manchay, there is a social distinction between people who live at the to and those who live at the bottom. When private water tankers come to the town to fill up local's water barrels, the tankers go to the lower part of the hill almost every day and satisfy their customers. The tankers, however, only go up the hill only once or twice a week. As result, those at the top do not receive as much water as those at the bottom of the hill. By placing the AWG at a strategic location at the top of the hill where the sun is bright, the AWG can first help the people who need the water the most. At the same time, we recommend utilizing the local church to aide in the fair distribution of water to the people. Since the American definition of fairness is not a global concept and the Peru may have a different concept of fairness, we want to work with an entity that understand what the people need. In Manchay, there is a high crime rate, according to Tony

Callery, a researcher in Manchay. His suggestion was to become friends with the local church to cut down on crime as well as to help with distribution. Our recommendation is to partner with the local church and ask them to advertise the technology, define fairness with a minimum amount of 20L given to each person (WHO standard), and guard the technology using the respect the church has with the community. The goal is to implement a solution that people will want to use, not a technology that they have to use.

We come to this conclusion, based on our interviews with someone who lived in Manchay, informal settlements experts, research on AWGs and their components, and research on the culture of Peru and Manchay.

When the team researched culture, we discovered we needed to use the church to make our solution culturally appropriate. By having the church distribute water, the AWG has a smaller chance of being stolen, and the church would find a "fair" way to distribute the water to the people. Also, we realized we needed to aid the people at the top of the hill because they are suffering from distributive injustice. When we researched climate, we realized that the most reliable source of water in Peru can come from the humidity in the air because climate change is affecting Peru's main river and Manchay is far from the ocean. When we researched different technologies, we saw that an AWG utilizes Peru's climate to its advantage. Also, when the team researched the different costs of the technologies, AWGs also were most effective for Manchay compared expensive technologies such as desalination.

This solution is the best in our unique social, economic, cultural, political, and environmental case. The solution is best socially and culturally because it uses religion to determine the fairness of the distribution of water. By having the church, the key entity of respect in Manchay, decide on a distribution plan, the local people will be more likely to respond to the technology. Since the task of distributing water will be the church's responsibility, the supposedly respectable, moral entity, may eliminate the team's preconceived bias of fairness and allow an appropriate definition of fairness to be decided by the representatives of the people.

Those who do not practice the religion will still be given access to water. Even though the church will have most say in the distribution of water, the team requires that each person receive at least 20L of water and that each person, regardless of their religion, be given water. Since the Roman Catholic church has a history of being generous to the poor and needy, we assume that the church will not discriminate against those of other religions.

Economically, the solution is the best because it minimizes power use through the different components, thus lowering energy costs. Also, the solution taps into a readily available source of water that does not cost money nor is regulated. Since the water is in the air, once the machine is on, the machine will produce water. We propose to have our sponsors pay for the initial investment and allow the local leadership entities to distribute water fairly and charge accordingly.

Because our technology is relatively self-sustainable with minimal human interaction, the solution does not involve too much government interference. Since Peru has a history of corrupt leaders, we created the solution to not allow the Peruvian government to interfere. Obviously government will still have some role because we are bringing in a foreign technology into the country, but our plan is to give the power of water back to the people, rather than the government. If the government were to help us, we would recommend that the government make the private water companies distribute to all people in Manchay, not just the lower part of the hill.

Our technology is also relatively environmentally friendly. AWGs do not produce harmful pollutants to generate water. In order to use external electricity whatsoever, we will install solar panels and a humidity regulator to produce water with sustainable energy at efficient times.

Implementation

The following implementation steps encompasses the analysis, the design, the pitch, the distribution, and the maintenance process of the solution.

To implement the solution, one must first analyze the potential technologies and unique components available. Our WPI team researched the target area of study for their social and cultural values. We researched Manchay, Peru, a place with high poverty and an environment filled with crime. Once our technological options, consisting of a river filtration system and numerous atmospheric water generators, were analyzed using a decision matrix based on water production, initial costs, replacement part costs, energy usage, and cultural acceptance, we developed a plan for how the AWG will be implemented in the target community with the help of experts. We conducted interviews with Professor Jiusto and Professor Peet. With the our data on different AWGs and their components, we developed a hypothetical AWG with estimated initial, water production, energy usage, and maintenance costs. We combined unique components from a multitude of AWGs to produce one AWG that increases the efficiency of the generator, and we developed a model to represent how to build our technology.

At this point in our implementation steps, we have been describing our analysis process. From this point on, we can no longer say what we did but can only say what we would do to further implement our technology.

The next step is to gain funding for the technology to build prototypes and test the design process. To gain funding, the team will prepare a scale model of the technology with component descriptions and a brief brochure on our solution. We plan to ask Peru's University of Technology and Engineering (UTEC), the same university that established the AWG billboard, because of their interest in AWGs and their home country. To be specific, our main contact may be Dr. Helard Álvarez Sánchez and his students because of his involvement with the billboard project. We hope our plans may interest Dr. Sánchez and he would be able to gain funding for the project in the same way the AWG billboard gained funding. The team plans to ask the school for enough money to build an AWG, run appropriate tests to ensure its effectivity, send the

AWG to Peru, and analyze the effects of it on the local community for a year. If the school can not provide funding, our WPI team may start a kickstarter online, building on the publicity of the original AWG billboard that UTEC produced in 2013. Either way, we plan to partner with the university to provide the Manchay with local support. Once our WPI team receives funding, our team will ask the government for its approval to work in Manchay and travel to Manchay. With a representative from the university (possibly Dr. Sánchez), our WPI team will speak to the local church leaders about a plan of implementation through a simple brochure similar to the one presented to the University. Once the local leaders accept the plan, the WPI team will implement the plan with the help of the local church leaders to include them in the process. By bringing in the actual technology from America, finding a location at the top of the hill with enough sunlight and humidity to power the technology, and creating a plan of distribution with the local leaders to distribute fairly and economically in the bounds of the technology's water production, the technology can established in the community. A system of charging the people for water will be developed, yet the costs will be kept to a minimum to ensure the fair use of the technology. Since our goal is to provide each person with at least 20L of potable water, we will make it a requirement that each person get a minimum of 20L and enforce the our major requirements through updates from the university maintenance reports. Once the leaders have decided on the method of fair distribution and familiar with the technology based on a guide from the designers, the leaders will market the technology to their people. For the next year, students from the university will observe the effects of the technology and distribution plan, using the measurements of success in the paragraph below. If the project has achieved at least an average of 6 for the quantitative survey, the project will be considered a success, and more AWGs will be produced and sent to Peru. A similar plan of talking to the local leaders and allowing them to decide on water distribution will be handled by university students.

Assessment

After the technology has been established in the community, University students will analyze the effects of the AWG on the people for one year. Each month the students will do a set of surveys for the people at the top of the hill and analyze the statistics on the technology. For qualitative data, the students will conduct 4 surveys: Satisfaction of the People, Satisfaction of the Leaders, Government Relations, and Sponsor Relations. For the Satisfaction of the People survey, students will talk to the local people and have them rate their satisfaction on their water experience with the technology on a scale of 1 to 10. 1 being that the trucks are superior and that technology is not working to people's satisfaction, while 10 being that the technology is satisfactory and reliable. For Satisfaction of the Leaders, a similar survey to the previous survey will be given to local church leaders to get their feedback. The students will also give the Government Relations survey to the local leaders. That survey will contain a scale of 1 to 10. 1 being that the government wants the technology gone, while 10 being that the government feels the technology is beneficial to the people. Lastly the Sponsor Relations survey will be conducted by the University students and will contain a scale from 1 to 10. 1 being that the University Students hate the technology and its performance for the people, while 10 being that the University Students love the technology and its performance for the people. For the quantitative data, the students will record the daily production of water, look for any patterns in the production process, and record the daily power usage and production from the technology. The statistics will be compared to the average per day. For the daily production of water, the statistics will be compared in liters/day because the metric system is used internationally. For the daily power usage, the student will compare in kilowatts/day. When the machine breaks or has complications, the students will record the damage, the reason for the damage, and the cost to fix the damage. Also, whenever the price of water, determined by the local leaders, changes, the students will record the amount of money charged per gallon. Local leaders will also keep track of the amount of money gained in accordance the amount of water distributed.

If the surveys produce an average of 6 or higher and the technology has a net economic gain, then the solution will be considered a success. We will then design another implementation plan to expand to other slums of Lima and potentially other areas that could utilize our solution.

<u>Conclusion</u>:

The overarching goal of the project was to provide potable water to the people of Manchay, Peru with a sustainable solution that did not infringe upon the people's right to water. Distributive injustice from private water companies, political corruption and negligence from the Peruvian government, and widespread poverty in the informal settlements of Peru have contributed to the purchase of expensive private water, poor water quality and living conditions, and a daily water per capita amount that is below human rights standards. All these factors relate to the lack of potable water in Manchay. To combat this injustice, the team designed a sustainable atmospheric water generator that could be implemented through the local church and UTEC to give 20 L of water to each person per day for around 500 people. By providing a new sustainable, outside water source with the help of local, respected entities, the solution will provide potable water to the people of Manchay, Peru.

During the research process, the team was limited by the amount of time and the resources given. Even though the team reached out to leaders on UTEC's Peruvian billboard project and other native Peruvians to discuss their experiences with informal settlements and water, the contacts did not respond. Also due to a lack of resources and expertise, the team was not able to construct a working AWG. Even though the team created a 3D model with estimated statistics, the team was not able to see the AWG become a reality. To understand the culture of Manchay, the team wanted to interview a local Peruvian who lives in Manchay. Due to a lack of time and resources to track down a potential person, the group could not talk with a local of Manchay. Instead of an interview with a local person, the group talked with a researcher in Manchay who spoke about the daily lives of the people. As a result of the team's limited time and resources, the team accomplished the 1st part of our implementation process: analysis of the problem and the creation of a plan to fix the problem.

To fill in the gaps of the analysis and continue on with the next steps of the implementation plan, the team would like for UTEC's students to continue our research. Since UTEC is in Peru, the students there will be contributing to a goal affecting real people who live in their home country. Our team believes that this motivation will propel the UTEC students to continue on with our research and make the solution become a reality and hopefully be implemented to other parts of Peru and the world.

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H. Conclusion

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Interview Questions

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Bio:

J. Scott Jiusto is an associate professor at WPI for Interdisciplinary and Global Studies. He has an educational background with a BS from Empire State College, State University of New York, an MA from Albany, State University of New York, and a PhD from Clark University School of Geography. At WPI, he connects with students to help them with their IQPs in centers around the world. He mainly works with informal settlements, water and sanitation provision, early childhood development, and sustainable livelihoods in South Africa.

Potential Information:

J. Scott Jiusto would help with our project because of his work in South Africa. He could give us valuable information on his work with water and sanitation as well as his work with informal settlements. Because the slums of Lima, Peru are both informal settlements and have difficulties with water and sanitation, his information would match nicely with what we need. By talking with him, we might gain ideas or leads to how we may solve the issues that we are dealing with.

Interview Participant: academic expert on informal settlements and water provision

Introduction:

1. Introduce myself
2. Thank them for taking his time
3. Description of project
4. Interest in his work
    a. My team and I are interested in your work with informal settlements and water provision. We understand you did important work in Cape Horn, South Africa in regard to these topics, and we have read your paper on informal settlements and drainage systems. Our location of study has similar characteristics, and we want to know more about the culture of informal settlements and how you provided water to the people of South Africa.
5. Relation to topic
    a. Lima, Peru is relatively near the coast and contains may informal settlements and potable water issues. We are interested in how you approached the problems with informal settlements.

Question #1: How and why did you get into WPI's global projects program?

Subquestion: How did you get to Cape Horn, South Africa and how were you involved with water?

I hope to get a general idea of what he has done in the past using these questions. I also want to see whether or not he has worked on the issues that we are dealing with and what his thoughts are on them.

Question #2: In Cape Horn, we understand you helped informal settlements. You talk about in your paper about how each informal settlement has its own characteristics. What are the key elements in an informal settlement to look for? How should we approach a community in a way that is culturally acceptable and effective?

Subquestion: How do we avoid planning in an ineffective way in the context of an informal settlement? You say in your paper how those who say "better planning will be of limited value." Can you expand upon that?

You say that if the technology is flexible, incremental, and informed by the kind of homesteader techniques, then it will be more effective? How might we apply these general tips in the context of a technological solution?

I hope to understand how he got past the barriers of informal settlements and learn about the issues I do not know about, using these questions. I want to answer objective 2 with this question by further determining what cultural, economic, political, and geographical barriers we will have when dealing with our solutions. If he has had experience with these types of settlements in the past, it would help us determine what we need to do. I also want suggest any technologies he might be aware of, if the conversation is leading to that topic in order to cover objective 1.

Question #3:How would you go about getting funding for the technology and implementation? We understand you worked with NGOs, but how did that all play out? Do you have suggestions as to how we might fund the project for the initial investment?

Subquestion: How would we go about looking at the life (all production stages) of a specific technology to minimize costs?

I hope to see how he funded his technologies and the steps taken to get to the final stages. I want to answer objective 2 to find a proper cost analysis for our technologies.

Question #4: We obviously want our potable water technology to stay in the community for years to come. Do you have any thoughts on how to manage and keep a technology sustainable?

You talk about the limited value of education in your paper. Do you think an educational plan is of value for our project and its scope? If it is, how much so?

> Subquestion: Once water is created, how would you distribute water in a fair manner?
>
> *This question is meant to answer objective 3 and see how he dealt with issues in his experience. We thought about an education plan, so I want to hear his opinion on the subject.*

Question #5: Any there any questions you think we should have asked and didn't ask?

Thank You: Thank you for your time and helpful information. If we have follow up questions, would it be OK if we email you.

Professor R. Creighton Peet

Bio:

Professor Peet has worked at WPI since 2000 in the IGSD department and has experience sending students to places like Namibia, South Africa, Costa Rica, Hong Kong, and other locations. Along with his involvement in the IGSD program, he heavily researches in the sustainable management of water. Working with both government and non-governmental organizations, he seeks to provide many informal settlements with water resources in an effective, sustainable manner.

Potential Information:

Professor Peet would provide information from his experiences with informal settlements and his research in water management. We hope to gain less information on objective and more information on objective 2 and 3. His experience with informal settlements will help us form a criteria for our technology, while his water management skills will help us develop a fair distribution plan. He can also help the team on the topic of maintenance.

Interview Participant: academic expert on water sustainability

Introduction:

1. Introduce myself
2. Thank them for taking his time
3. Description of project
4. Interest in his work
    a. My team and I are interested in your involvement in the Interdisciplinary and Global Studies at WPI. We would love to hear more about your interest in water sustainability and the projects that you have done in the past with students to combat issues with this topic. We would also like to explore the ways in which you have explored proper water management in the past.
5. Relation to topic
    a. Because people in Pachacamac have an issue accessing, using, and managing potable water, we would like to get your perspective on how we can manage our potential solutions to help create a sustainable water source for them in the future.

Question #1: How and why did you get into your work of study?

Subquestion: Where did you most recently have a project? And how did that go?

Question #2: Have you had any projects in the past that dealt with the chief concern of lack of potable water?

Subquestion: Which solutions to your past projects would be applicable to the area of interest that we are focusing on?

Question #3: I know that your work in Namibia and the management of River basins there involved the cooperation of government and non-government forces. How has your experience with the government, organizations and the people of Namibia shaped your understanding of the relationship between them?

Subquestion: The government and the people of the slums of Lima, Peru generally have a distrust of one another due to the corrupt nature of the government and the squatting lifestyle of the people living in the slums. Do you believe that our involvement in the informal settlements of Peru would be an issue with the government there? Even if we came up with a solution that didn’t involve the government at all, could our project be interfered with by the government simply due to the poor relationship between the people and the government there?

Question #4: Explain our two solution options. Which technology do you think would be the most beneficial and sustainable for the people of Pachacamac if it were applied there?

Subquestion: How would you distribute the water we collect in Pachacamac evenly and fairly for either one of our solutions?

Question #5: Any there any questions you think we should have asked and didn’t ask?

Thank You: Thank you for your time and helpful information. If we have follow up questions, would it be OK if we email you.