Safe Water Evaluations in the Peruvian Amazon

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Abstract – Although fresh water is an abundant resource in the Peruvian Amazon, thermotolerant coliform contamination, measured as high as 1024 colonies/100ml, renders much of it unsafe for human consumption. Many villages have neither the means to purify their water nor to understand why purification is warranted. An engineering group from the University of Alabama, facilitated by Nature and Culture International (NCI), visited the Amazonian village of Ayacucho to perform an evaluation of the residents' attitudes, quality of water sources in the immediate area, and an existing water treatment system. These objectives were established prior to leaving and based on feedback from a previous trip to the area. Water samples taken were measured for turbidity and thermotolerant coliform contamination. Results indicate that the local water sources are contaminated by thermotolerant coliform and that the water treatment is reducing these contaminants. In total, a better understanding of the village's concerns and issues was gained despite the language barrier. Future trips will continue to work with the local population to better educate them on the need for treated water, test for other contaminants and set up a lab and train local NCI personnel in water testing.

Index Terms – developing countries, rural areas, water treatment, water testing, water use survey

INTRODUCTION

In 2005, the College of Engineering at the University of Alabama (UA) established a partnership with the Nature and Culture International (NCI), a non-government organization. NCI developed the Program for Conservation, Management, and Sustainable Use of Biological Diversity in the Region of Loreto (PROCREL) to help conserve the extraordinary biodiversity of Loreto, the largest governmental region in Peru containing 90 million acres of Amazon rainforest. A key element of the program is promotion of a strategy of “production conservation” in which local populations are trained to sustainably manage and conserve their natural resources while carving a living from the forest. This approach is intended to preserve the biodiversity of the region as a resource for present and future generations, while substantially improving the livelihood of the local people. NCI, UA and five villages participating in PROCREL have strengthened their collaboration, established in 2005, through annual service learning project installations that include water, land, soil and community surveys, sanitation projects and solar installations. These infrastructure projects provide an incentive and reward to villages participating in the production conservation program.

The goal of the initial 2006 UA service-learning trip to the area was to establish relationships with an NCI liaison and five villages as well as to determine if there were appropriate projects for future years. During informal public and private discussions in the village community center and private in-home surveys, the main needs of the village were identified as sanitary systems, lighting, clean water, and communications with the outside world. Previous trips have addressed sanitary and lighting concerns but the 2010 trip was the first to address drinking water quality issuesⁱ.

This paper details water quality monitoring during the 2010 service learning study in Peru by UA.

OVERVIEW

The village of Ayacucho, our target community, is approximately four hours by high-speed boat from the city of Iquitos and is populated by around 30 Spanish-speaking families. Figure 1 shows the location of the village with respect to Iquitos and Lima, the capital of Peru. Ayacucho borders an Amazonian tributary that floods annually during the rainy season which is December to May.

FIGURE 1
MAP OF PERU^{II}

The layout of the village shown in Figure 2 is typical of the region with thatched huts centered on an open field. A school, a village community center, and a water treatment tower also border the field. All of these structures are elevated due to the flooding that occurs. A nearby American-owned lodge that relies on villagers from Ayacucho for its workforce had recently installed the water treatment tower in the village; however, no testing of the system has occurred to date. The focus of this project trip was to evaluate the village's water usage, quality and needs and to expand solar installations started by the previous group in 2008.

FIGURE 2
DRINKING WATER SOURCES (S) AND SAMPLING LOCTATIONS (X) AROUND AYACUCHO

OBJECTIVES

The students were divided into project groups and the water project team was challenged with the following goals:

- To gain a better understanding of the residents of Ayacucho's water usage and needs.
- To determine the effectiveness of the installed water treatment process.
- To identify the contamination in alternate water sources around the village.

METHODS

Meetings were held at UA prior to departure for Peru to gain an overview of past projects, prepare for the current projects and perspective on the region, village and its indigenous people. Upon arrival to Ayacucho, a village meeting was held at the village hall. Introductions were made by the NCI liaison between the locals and the UA team. A project overview was provided to the locals for their edification and to solicit their involvement. Many locals had participated in previous trip's activities and understood the project framework. In order for UA to return, the village had to agree and decided to participate. The floor was opened to questions and answers were provided to the best of the team's Spanish speaking ability and working through the translator as necessary. Upon the meeting's closure the members of each task-group began their respective assignments.

Survey of local population

The local women, who have the responsibility for collecting the family's cooking and drinking water, were asked to congregate in the village hall to take the surveys which had been developed and were administered by UA students, shown in Figure 3. The survey was initially developed prior to departure, in a free response format in Spanish. Topics included: source of water for cooking and drinking, how they treated water that did not come from the treatment system, and their overall impression of the treatment system. A local woman who worked for the NGO helped with translations. Upon administration of the survey it quickly became evident that the locals were unable to provide adequate responses to open ended survey questions due to a combination of their literacy levels and the Spanish dialect used. Therefore, our initial survey was restructured in the field with input from local NGO workers and reformatted as multiple choice type questions that were read to the participants. Furthermore, Spanish vocabulary was chosen to better reflect the dialect of the village. The following day the team members visited various homes around the village to administer the new surveys. Administering surveys in homes was also a better strategy as it allowed us to observe water use practices in the home.

FIGURE 3
CONDUCTING THE INITIAL SURVEY

Water Treatment in Ayacucho

Prior to water quality sampling, it was necessary to first understand the water treatment process and water use patterns by villagers. The sampling scope was determined as a result of observations of the treatment system, conversation with inhabitants of Ayacucho and results of the survey.

The treatment system pumps water from a lagoon behind the village that is refreshed seasonally when the river floods to the top of the treatment tower. The water then flows under gravity through a chain of treatment processes. A basic schematic of the treatment train is shown in [Figure 5](#). The source water is pumped 10m to into a 1000L PVC storage/feed tank at the top of a the treatment tower. A drain valve 6" from the bottom of this tank controls the flow of water by gravity to the units below. A tank cleanout valve at the bottom of the tank allows for removal of settled solids. The next level contains a tank identical to the first that serves as the chemical (alum and chlorine) contacting tank. Water from the second tank flows by gravity through a series of three packed bed sand column filters, and then to a final "hot tub" type polishing filter.

FIGURE 4

WATER TREATMENT TOWER, STANDING AT THE EDGE OF THE PUDDLE IN THE VILLAGE SQUARE.

FIGURE 5

WATER TREATMENT PROCESS

In the batchwise treatment flow path, Figure 4, the treatment plant receives surface water pumped from the intake point to the first tank at the top of the tower. This first tank serves as a pre-settling basin where suspended solids are allowed to settle for 2-3 hours. The top tank is then manually drained by opening a valve and the water flows into the lower tank. This tank serves as a chemicals contacting, coagulation and settling basin. At this point in the treatment process, six capfuls (a capful is roughly 7 mL) of both alum and chlorine are added to the tank containing 1000 liters of water and are manually mixed with a large paddle. Mixing is then

stopped and the floc formed by the alum is allowed to settle. The valve on the second tank is then opened to allow the settled water to flow by gravity through the three sand filters, Figure 6. The sand filters can operate in series or parallel and can be backwashed individually or in parallel when head loss becomes excessive. Each can be isolated for removal and cleaning without interrupting the treatment process. The final stage was a “hot tub” type filter to capture any media carryover from the sand filter particularly following backwashing. An outflow valve completed the treatment train. The “hot tub” filter, shown in Figure 7, is a basic cartridge filter commonly used in hot tubs or as part of whole water house filters in developed countries. It is composed of a pleated, non-woven spun-bonded, polyester fabric. This type of filter is difficult to come by in a remote location such as Ayacucho, but it could be backwashed and reused or brought by boat from Iquitos during regular NGO visits to the villages.

FIGURE 6
SAND FILTERS

FIGURE 7
"HOT TUB" FILTER

Water Sampling

To see whether the optimal amount of chemicals was being used in the treatment process, samples were taken from the intake point of the system. Various combinations of both alum and chlorine were added to the pre-settled water to see which combination would result in the best overall water quality. To simulate the treatment of the water, an ECE Minimix laboratory mixer, shown in Figure 8, was brought to the field from UA.

The mixer unit, called the "jar test" in the water industry, is used to optimize chemicals (typically flocculation agent(s), pH buffers (lime typically) and/or chlorine doses for turbidity removal). Known variable amounts of chemicals are added and the mixer is run on conditions that simulate what is happening during the treatment process. For a typical plant this would be fast speed then slow speed then zero speed: to emulate the conditions of rapid mixing (coagulation), slow mixing (flocculation) and settling (sedimentation). In the villages we would decide on how the test would progress depending on the type of treatment and measurement of hydraulic residence times in each stage of treatment.

The turbidity is measured at the end of the test, and the jar (i.e. water container) with the lowest turbidity represents the best dose of that chemical. When all chemicals have been tested the pH is adjusted to the optimized value (from the pH buffer chemical jar test) and the test is repeated with quantities of chemicals closer to the optimized dose to clarify the exact doses at the optimum pH.

FIGURE 8
ECE MINIMIX LABRATORY MIXER

For microbial analyses samples were taken at the pump intake, tank 1 and the spigot at the treatment plant outflow valve. Samples were also taken from various locations around the village as shown by the X's in Figure 1. Samples#1 and #2 were taken from the muddy water surrounding two houses in the village. Sample #3 was taken from what is a field in the center of the village in the dry season, but was then a large puddle. The remainder of the samples were taken from the river, both close to shore and farther out.

The samples were collected in 100 ml polypropylene bottles that were rinsed three times in the water from which the sample was taken. The samples were kept cool and out of the sun until they could be processed.

The samples were tested for thermotolerant coliform bacteria (TTC) using an OXFAM DelAgua test kit. TTC was used as a measure of contamination. The presence of TTC in a sample of water indicates fecal contamination which may mean that other pathogens are also

present in the sample. The World Health Organization states that zero TTC should be present in a 100ml sample of water.ⁱⁱⁱ

The DelAgua test kit, shown in Figure 9, is a mostly self-contained kit whose primary function is field testing of water samples for TTC. The kit was used previously by our group in Cambodia^{iv} and is used worldwide for water testing in remote locations.^{v,vi,vii,viii} The kit also contains an instrument for measuring turbidity. To test for TTC, a water sample is drawn through a membrane filter, which strains out the bacteria. The membrane is placed on a selective growth medium in a Petri dish for incubation. The kit also fills the role of incubator and can be powered by AC or DC. DC power can come either from an external battery, such as in a vehicle, or from the kit's internal battery which can power the incubator for up to five cycles per charge. Perhaps the most innovative aspect of the DelAgua kit is the method for sterilizing the TTC testing apparatus. Methanol, obtained locally in Iquitos, is poured into the stainless steel cup and ignited and then quickly and carefully smothered using the funnel. The burning of the methanol in this low-oxygen environment produces formaldehyde gas, which sterilizes the apparatus. Other necessary items such as a lighter, a kettle to boil water for sterilization, and syringes to use for liquid measurement were also purchased in Iquitos.

FIGURE 9
DELAGUA TEST KIT^{ix}

Since the membrane would also strain out debris suspended in the water, eventually clogging the membrane, the volume of the sample was varied according to how turbid the sample appeared to be. To eliminate variance due to the different sample sizes, the actual sample size used was recorded and the results were standardized to a 100 ml sample size. The membrane was incubated on the growth medium at $44 \pm 0.5^\circ\text{C}$ for approximately 16 hours. After incubation, the TTC colonies were counted. These testing procedures are recommended by the kit's manufacturer and are consistent with EPA method 1604^x.

This kit was also used to measure the turbidity of the water at different stages of the treatment process. The turbidity of certain samples from steps in the treatment process was measured using the turbidity tube included in the DelAgua kit. The device is a clear plastic tube with a marking at the bottom. Water is poured into the tube until the marking is no longer visible. The tube is graduated logarithmically to display the height of the water column in turbidity units (TU). The proper use of a turbidity tube has been described by the EPA^{xi}.

There was no constant supply of electricity to operate the incubator. Thus, the kit's internal battery was invaluable. The lack of electricity also meant that the electric kettle brought along to boil water for sterilization was useless, so that everything had to be sterilized using methanol and allowed to dry.

Additionally, since the samples were gathered during the day and had to be processed within 12 hours of collection, they had to be prepared for incubation after night had fallen. The flashlights and kerosene lamps used to illuminate the workspace attracted all manner of insects, making it difficult to meet the standards of cleanliness that must be maintained when doing microbiological work.

To test for possible contamination resulting from these less-than-ideal conditions, a sample of water that had been boiled over a fire and allowed to cool was also tested in the same manner as the field samples. This sample showed zero TTC contamination, demonstrating that the sterilization and cleanliness protocols, while rudimentary, were effective.

RESULTS

The survey results are presented in [Table I](#). Ten people, representing approximately 33% of the households, were interviewed (the entire population of Ayacucho is about 100.) The ages of the people ranged from 10 to 45 with a median of 25. Three of the respondents were children (age 10 to 12), however it is important to note that village children of this age are fully engaged in water collection for their families and share in household responsibilities and child raising.

TABLE I
SURVEY RESULTS

Question	Choices	Response
Where do you get your drinking water?	Treatment	
	plant	70%
	River	0%
	Both	30%
Where do you get your cooking water?	Treatment	
	plant	30%
	River	10%
	Both	60%
If you use river water then do you boil it?	Always	60%
	Sometimes	40%
	Never	0%
Do you think the water makes you sick?	Yes	70%
	No	30%
Do you think the water tank has made life better?	Yes	100%
	No	0%
Do you think you are healthier than before?	Yes	100%
	No	0%

The treatment plant seems to have been integrated into the lifestyles of the majority of the village respondents. The health benefits are apparently clear to the respondents, yet they have not fully adopted its use.

The results from the TTC test on these samples are summarized in [Table II](#). Table II references the numbers assigned to the collection sites in Figure 1.

TABLE II
TTC RESULTS FOR UNTREATED DRINKING WATER SOURCES

Number on Figure 1	Description	TTC colonies/100 ml
1	House 1	928
2	House 2	280
3	Village field	0
4	River bank at village center	175
5	Middle of river at village center	128
6	River bank upstream of village	1024
7	Middle of river upstream of village	40
--	Field blank	0

River samples were not taken downstream of the village due to communication difficulties between the team and the Spanish-speaking boat pilot. However, the majority of dwellings in the village are located upstream of the village center. So while samples downstream of the entire village would be ideal, the samples that were able to be collected do provide insight into the effects of the village on the river.

Generally, the TTC counts were in agreement with expectations of water quality. It was expected that the water around the houses would be quite dirty because of the high turbidity and the presence of various animals in and around the house. The higher contamination close to the shore of the river makes sense, since that water is usually not flowing as quickly. The increase in contamination between the middle of the river samples taken upstream of the village and at the village center was also expected since sewage treatment in the village is minimal at best. The large amount of contamination close to the bank upstream of the village is probably due to recent activity by nearby people or animals. The lack of contamination in the village field was surprising and discussed in further detail below.

[Table III](#) shows the TTC count and turbidity as water progresses through the village's treatment process.

TABLE III
TTC RESULTS FOR WATER TREATMENT PROCESS

Source	TTC colonies/100 ml	Turbidi ty (TU)
Before pump	366	16
Top tank	4	8
Output valve	14	0

Turbidity was reduced between the intake and top tank by settling in the top tank. Between the top tank and the tower's output, turbidity was removed by chemical treatment in tank 2, and the "hot tub" filter.

Upon inspection of the treatment system, it was noted that the sand filters were being bypassed in the treatment process (so the water taken from the output valve had not been through these filters, though it had received all other treatment). It was eventually determined that this was done purposely by the villagers because they were under the impression that these filters were contaminated by bacteria. To investigate this, the filters were returned to the system and water was run through them. To isolate the effect of the sand filters, a valve leading to the "hot tub" filter and output valve was closed and the samples were taken directly from the filters through a valve located on the bottom of the last filter. These samples showed zero TTC contamination though other contamination, such as waterborne parasites, cannot be ruled out.

The data indicates that the chemical treatment in tank 2 is successful in reducing TTC by 99% and turbidity by 50%, and the overall treatment process (excluding the sand filters) removes 96% TTC and 100% turbidity.

When it came time to optimize the chemical treatment of the water, the mixer unit was no longer functioning and the remoteness of the location precluded any attempts to find a substitute. Due to this equipment failure, optimization of the chemical dosing could not be performed.

DISCUSSION

The UA team followed their established objectives to the best of their abilities. Although all were not achievable, due to various obstacles and unforeseeable circumstances, valuable lessons were learned and experiences gained that will be valuable to both the students and future projects. Students led a successful comprehensive water quality evaluation with additional detail discussed below.

Surveys

Further reflection among the team and our NCI liaison indicated that a more informal discussion based method would be more suitable to obtain local opinions. Villagers are unaccustomed to the direct questioning approach inherent in typical survey methodology and unable to elaborate on their feelings or understanding.

Water Treatment System

The water treatment system does provide the village with cleaner water than they could otherwise procure. The system effectively reduces the turbidity of the water. The increase in TTC between the top tank and the output valve is puzzling. More tests would be required to

determine if some intermediate step is causing contamination, though the absence of TTC in the sand filter samples suggests that this may happen in the "hot tub" filter.

Despite the villagers claims, our team found no evidence to show that the sand filters are contaminated by TTC. It is possible that the sand filters were bypassed because they were becoming clogged and reducing the flow rate of the system. If this were the reason the filters were being bypassed, backwashing or scraping the filters regularly, could solve the problem. Furthermore, the maintenance and cleaning schedule of the tower was not known by any of the villagers who were asked and no one in the village was responsible for upkeep of the tower. Training one or more of the villagers to operate the tower properly would greatly improve the likelihood of successful function.

A major concern noted about the current treatment system is that the source is a lagoon that is refilled when the river floods. Some of the home latrines empty into this same lagoon. Questions from the residents about why the tower takes water from the same place their latrines empty supported our data that the river would be a better source for water for the treatment plant in terms of initial quality. However, although the TTC data for the pump intake versus the river water favored the river, the location of the intake on the river would require a follow-up study of variables such as TTC counts and water level as they fluctuate throughout the year.

Water Sources

As expected, the standing water around the houses showed high levels of TTC contamination. While the team observed nothing to suggest that this water is used for drinking or cooking, to get anywhere in the village during rainy season one must walk through this water, usually barefoot, making it a health risk.

Surprisingly, the sample of water from the vast shallow puddle in the village square showed no TTC contamination, even though on one occasion a small child was observed urinating into it, and a dead frog was observed floating there. This is believed to be due to the fact that, unlike the water in front of the houses which was muddy and sometimes nearly half a meter deep, this water was clear and shallow (no more than about 15 cm.) Walking through this puddle to get to various locations around the village square was often uncomfortable because the water was heated to a surprising degree by the equatorial sun. Also, since the water was clear, the ultraviolet light from sun is believed to have helped sterilize it. This finding could possibly be applied to the design of a solar water treatment facility for the Peruvian Amazon and similar areas.

The quality of the river water is perhaps most directly pertinent to the village's health since, as indicated in [Table I](#), it is a significant source of water for the village. The increase in TTC contamination between sampling points #7 and #5 in [Figure 1](#) may indicate pollution added to the river by the village. None of the samples taken from the river are safe to drink without some form of treatment.

CONCLUSIONS

Overall, the locals have accepted and are pleased with the system and believe that it is making them healthier. The team was able to conclude the treatment tower in Ayacucho is not operating as intended because the sand filters are bypassed. However, the current water treatment does reduce TTC contamination by 96% and turbidity by 100% using chemical treatment and a "hot tub" filter. While no evidence of TTC contamination in the filters was found, further study is

required to determine whether concerns as to the filter's cleanliness are justified. In addition, the team learned valuable lessons about field preparedness and equipment redundancy are now included in our standard operating procedures (SOPs) For future projects

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