




Local Water Network Rectification in Krabi, Thailand

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WPI

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A joint proposal of recommendations for the water quality and water scarcity issues affecting the villages of Baan Tha Thong Lang and Baan Tha Lane in Krabi, Thailand submitted to the Population and Community Development Association and Rotary Club of Bangkok by the students of Worcester Polytechnic Institute and Chulalongkorn University.

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Abstract

This project aided the Population and Community Development Association to address the water quality and quantity problems of two villages, Baan Tha Thong Lang and Baan Tha Lane in Krabi, Thailand. Our team observed the water systems, surveyed villagers, interviewed experts, and conducted water tests for non-drinking standards of the water supplied by both systems. Our results indicated that the water in one well of Baan Tha Thong Lang exhibits high levels of hardness while the water system in Baan Tha Lane does not provide enough water to the village. We recommended that if the PDA has the funding to install a 170,000฿ chemical precipitation system in Baan Tha Thong Lang and dig a 1,125,000฿ well in Baan Tha Lane, it will greatly improve the quality of life for over 600 rural villagers.

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Executive Summary

Introduction

Poor water quality and water scarcity are two major issues affecting people on a global scale. The United Nations has estimated over 780 million people do not have access to quality water. Quality water is water consumed or utilized without major physical repercussions to the people or distribution networks involved. Similarly, over 1.2 billion people live in areas without access to a sufficient amount of water (United Nations, 2007; 2013). Poor quality water and insufficient water supply can have a number of adverse health effects and negatively impact the infrastructure of water systems.

In 2004, a tsunami generated by a 9.1 magnitude earthquake in the Indian Ocean devastated many of the rural villages on Thailand's western coastline. This disaster damaged the water distribution systems of numerous communities and left them with poor water quality and an insufficient supply of water. This was especially the case for the two villages of Baan Tha Thong Lang and Baan Tha Lane, located on western coast of the southern province of Krabi.

Our sponsor, the Population and Community Development Association (PDA) is a non-governmental organization that works to improve the quality of life for Thai citizens. Their mission is to help rural villages improve their access to clean and abundant water. The PDA focused on Baan Tha Thong Lang and Baan Tha Lane when they learned that the two villages were experiencing complications related to poor water quality and water scarcity. However, they did not know the severity of the problems and their impact on the villagers. Hence, the PDA asked our team to identify the villagers' opinions of the systems, the defects exhibited by their components, and evaluate the quality of the delivered water.

Goal, Objectives, and Methods

The goal of our project was to aid Baan Tha Thong Lang and Baan Tha Lane improve their current water systems by increasing the quality and amount of water the villagers received. To accomplish this goal our team identified four objectives and performed several methods. The information we gained from objectives one to three allowed us to complete our fourth objective; developing recommendations to improve the water systems. Figure 1 provides a diagram of this process.

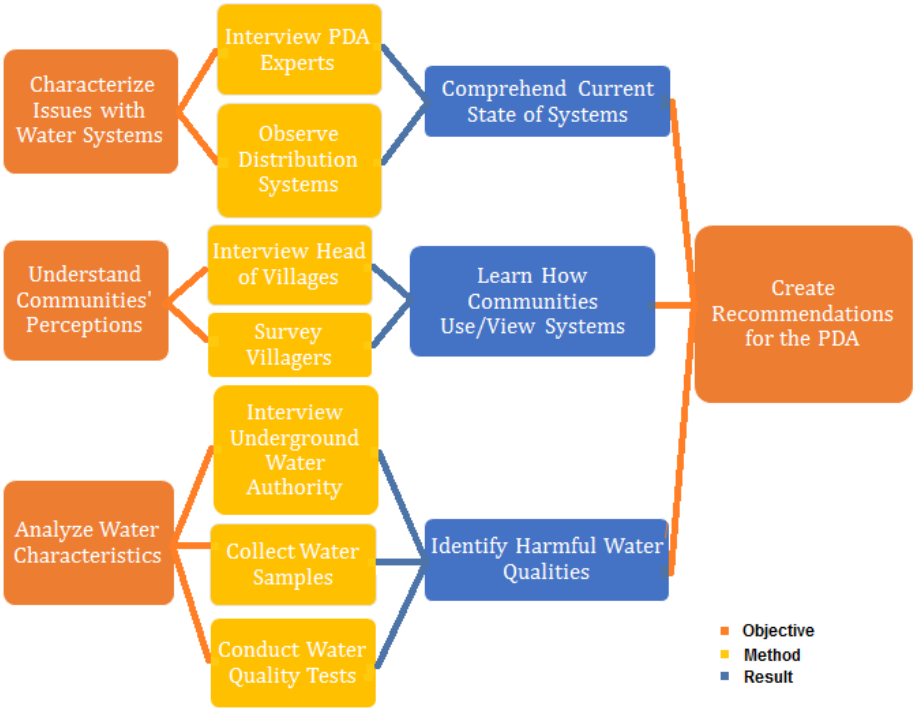

Figure 1: Methodology Flow Diagram

Our first objective was to characterize the problems with the water systems. At each community, our team recorded the geographic location of the wells and water tanks, created diagrams of the layouts of the systems, and noted any corrosion or leaks in the visible pipes and pumps. The team also conducted an interview with Khun Aumnuay, the head of the PDA in Krabi, to learn more on the water distribution systems of the two villages. During this interview we realized that we needed to break our project into two parts: water quality in Baan Tha Thong Lang and water scarcity in Baan Tha Lane.

Our second objective was to evaluate the villagers' uses and concerns with the systems. We created customized surveys for each village with a number of common questions but with several additional questions specifically targeted at each community's unique perceived problems. The team went door to door and conducted surveys with residents. In total, we surveyed 21 people in Baan Tha Thong Lang and 16 people in Baan Tha Lane. Our team used these surveys to identify the villagers' water usage, their opinion on the systems, health and infrastructure problems due to the quality of the water, and improvements they would like to see implemented.

Our third objective was to analyze the characteristics of the water supplied by the systems. To complete this objective, the first task was to create a specific list of water testing parameters for non-drinking standards, the second was to learn the procedure for collecting the water samples and purchase the necessary materials for sample collection, the third was to collect samples from the wells in Baan Tha Thong Lang and Baan Tha Lane, and the fourth was to test the water at Chulalongkorn University. This procedure enabled us to gather information on the specific properties of the water most detrimental to the villagers and their distribution systems.

Our fourth objective was to create recommendations for the PDA on how to alleviate the poor water quality and quantity in the villages. Our team completed three tasks to create our recommendations. The first task was to analyze the survey and

interview data through coding and statistical visualization, the second task was to evaluate the testing results from the water samples, looking for parameters outside the acceptable values, and the third task was to create estimated ranges of costs for the recommended solutions.

Findings

The completion of each objective led us to compile results about the most relevant problems with the systems' infrastructure, concerns of the villagers, and properties of the water. We list our most important results below, which provided the necessary information for developing our recommendations.

Neither Baan Tha Thong Lang nor Baan Tha Lane presented damaged water systems, however Baan Tha Lane faced a chronic water scarcity. For Baan Tha Thong Lang, the village received its water from four wells in various locations throughout the area. Each of these four wells supplied water to different areas of the village. 3 out of the 4 wells did not include water treatments and the water flowed directly into local households. The fourth well had a system to filter out excessive amounts of iron in the water.

We found that Baan Tha Lane acquired its water from two wells located 1.2 kilometers away from the village. These wells drew water from the same underground water source. The water from these wells passed through two other villages before reaching Baan Tha Lane. However, the wells were unable to provide a sufficient amount of water to supply all three villages and as a result, Baan Tha Lane received almost no water.

Additionally, our team did not find any apparent signs of disrepair such as leaks or corrosion during our physical examinations of both water systems.

The villagers in Baan Tha Thong Lang are most concerned with water quality, and the villagers in Baan Tha Lane are most concerned with water scarcity. 19 out of the 21 community members we surveyed in Baan Tha Thong Lang did not believe the water supplied by the wells was safe to drink. 2 of these residents who felt the water was unsafe to drink reported that they consumed the untreated water because they could not afford buying bottled water. Therefore, when we asked the villagers' interest in improving the water quality, 18 of the 21 expressed they would like to see it improved for drinking standards, while the rest did not think the system required any changes. From these results, we concluded that the villagers desired their wells to provide higher quality water.

Of the 16 villagers we surveyed in Baan Tha Lane, 13 stated they did not have enough water throughout the entire year. One of these villagers informed us that she had not received water for one month. The remaining 3 villagers lacked water only in the dry season. This data helped us find that water scarcity was the main issue that affected the villagers in Baan Tha Lane. All of the surveyed villagers reported water scarcity at some point during the year and that they would like to see the system improved to provide a constant supply of water.

One well in Baan Tha Thong Lang had high levels of hardness, and wells in both Baan Tha Thong Lang and Baan Tha Lane had low pH levels. Our team compared the composition of the water samples from the wells with the Thai Department of Groundwater Resources' standards for non-drinking water. We found that three wells in Baan Tha Thong Lang and the well in Baan Tha Lane had low pH values. Additionally, we discovered that one well in Baan Tha Thong Lang had exceedingly high hardness levels. We determined that the pH levels were not a pressing

issue after consulting with experts and reviewing previously conducted water tests by the PDA. This was because pH varies seasonally, and the levels found in these wells do not currently present threats to human health. The high hardness, however, was a problem we needed to address, as it made the water unsuitable for non-drinking purposes.

A water softening process should address the water hardness in Baan Tha Thong Lang and a new water source should address water scarcity in Baan Tha Lane. Taking into consideration all of the findings from the analysis of our surveys, water tests, and physical inspection to the water systems, our team identified the most urgent problems to address in Baan Tha Thong Lang and Baan Tha Lane. We concluded that improving the water quality was of greatest importance in Baan Tha Thong Lang. Therefore, we compared costs, effectiveness, convenience, and environmental impact of multiple methods for treating water hardness. Ultimately, we selected chemical precipitation as the best treatment option and provided an approximate budget range for the installation of the system. We present this information in the following section.

For Baan Tha Lane, we determined that remedying water scarcity was the greatest priority, with water quality being supplemental. We evaluated different configurations of an improved water network which included the construction of a third well. These configurations consisted of ideas from the local government, the PDA, and our team. These configurations take into account costs, ability to supply enough water to the village, and compatibility with the current system. We created approximate budget ranges for the three proposed water network configurations. Furthermore, we believe that this well will be deeper than the existing ones, so high levels of iron may appear. Therefore, we also recommend manganese greensand filtration to treat the iron in this new well.

Finally, from our surveys we found that both Baan Tha Thong Lang and Baan Tha Lane villagers would like to have their water reach drinking standards. However, as we discovered this desire during our field work in the villages, we could not test the water for drinking purposes and receive the results before the project ended. Thus our recommendations for future research are that the PDA should test for these parameters and develop a plan to bring the water to drinking standards. We recommend the FCU-8 machine as the best option to treat the water from the wells in these two villages to reach drinking quality levels.

Recommendations

Table 1 below outlines the recommendations we developed for the PDA and which we described in the last section of our findings. We provide estimated cost ranges, advantages and disadvantages for each solution.

Notice that for Baan Tha Lane, we are not recommending one option over the other two as we were unable to gather sufficient information to ensure any of the options will completely resolve the scarcity. Through further research, the PDA should choose the best option based upon its budget constraints and the highest potential to alleviate the problem.

Table 1: Summary table of recommendations for water system improvemnts

	Baan Tha Thong Lang	Baan Tha Lane				Baan Tha Thong Lang and Baan Tha Lane
Name	**Chemical Precipitation**	**Option 1**	**Option 2**	**Option 3**	**Manganese Greensand Filtration**	**FCU-8 Treatment System**
Estimated cost range (Baht)	150,000 - 190,000	188,000 - 392,000*	410,000 - 614,000*	1,026,000 - 1,229,000*	90,000 per 10 m^3 tank.	58,000
Pros	Treats water hardness Keeps current infrastructure	Least expensive option Keeps current structure	Bypasses the first community Keeps current storage tank	Ensures Baan Tha Lane receives own supply of water Addresses community's recommendations	Presents no concentration of chlorine, no sulphur dioxide, no increase of total dissolved solids, no backwash	Relatively inexpensive Proven reliability Treats to drinking standards
Cons	Relatively inexpensive High maintenance	Still must travel through two villages to reach Baan Tha Lane	Requires new piping structure Water is shared with second community	Very expensive	Must be consistently replenished with a chlorine or permanganate solution.	Requires single distribution site

*This price does not include iron treatment system.

Conclusions

Our team culminated our data, findings, and conclusions into a set of recommendations to improve the water systems of Baan Tha Thong Lang and Baan Tha Lane. By following the solutions discussed above, the PDA will be able to provide high quality water to over 500 residents of Baan Tha Thong Lang and allow more than 100 residents of Baan Tha Lane to have a constant and reliable source of water. Additionally, the implementation of these solutions will result in a reduction of the villagers' cost of living as they will no longer need to buy bottled water for drinking and cooking purposes. Finally, if this project is successful, these villages may serve as examples for similar problems present in a number of nearby villages in southern Thailand.

1. Introduction

The lack of clean and plentiful water is a major global issue. According to the United Nations, over 780 million people around the world do not have access to quality water (United Nations, 2013), which leads to approximately 2.18 million deaths annually (Rijsberman, 2006). Quality water is water consumed or utilized without major physical repercussions to the people or distribution networks involved. In addition to proper water quality, people also need a sufficient amount of water for their health and daily needs. The United Nations estimates that 1.2 billion people, almost one-fifth of the world's population, live in areas without proper access to water (United Nations, 2007). The effects of water deprivation include decreased mental performance, an increased risk of cancer, and death if dehydration persists for too long (Kleiner, 1999). As such, water quality and quantity are often associated with each other and affect many developing countries and rural regions that lack the resources to improve their conditions.

Approximately 80% of Thailand's 7.3 million impoverished people live in rural areas, including the country's western coast (The World Bank, 2014). In 2004, a tsunami generated by a 9.1 magnitude earthquake in the Indian Ocean devastated many of the rural villages on Thailand's western coastline. The country suffered from estimated economic losses of 14 billion baht, 4500 houses destroyed, and 8000 people dead or missing (Srivichai, Supharatid, & Imamura, 2007). The disaster also damaged the water distribution systems of numerous communities and left them with poor water quality and an insufficient supply of water. As a result of the tsunami's destruction, communities in this region struggled to acquire suitable water for their daily needs. The

Thai government and several non-governmental organizations constructed wells and treatment systems following the tsunami to aid the affected communities.

A large number of the water distribution systems built after the tsunami utilized groundwater sources. In Thailand, more than 10,000 wells use groundwater sources capable of producing over 1,120 million m^3/acre (Foster, 2008). However, underground water sources such as aquifers often contain contaminants including heavy metals, salts, and excess minerals that can make the water unsuitable for domestic purposes (Saraphirom, Wirojanagud, & Srisuk, 2013). In addition, the water level of aquifers can run low or even dry throughout the year if several communities have to share a single water supply. Water related issues like these can negatively impact communities that are dependent on groundwater sources.

Our sponsor, the Population and Community Development Association (PDA), is a non-governmental organization that works to improve the quality of life for Thai citizens. A major focus of the PDA is to help rural villages improve their access to clean and abundant water. The PDA focused in Baan Tha Thong Lang and Baan Tha Lane when they discovered that the two villages were experiencing complications related to poor water quality and water scarcity. The villagers in Baan Tha Thong Lang reported poor water quality from their well system, while Baan Tha Lane's villagers complained of an inadequate supply of water. The PDA office in Bangkok did not know the severity of these problems or their impact on the villagers. Hence, they asked our team to identify the villagers' opinions of the systems, any damage with the infrastructure, and the quality of the delivered water. We then provided recommendations on how to improve the conditions of the two water systems.

Accordingly, the goal of our project was to aid the two villages of Baan Tha Thong Lang and Baan Tha Lane in Krabi, Thailand improve their water systems. In Baan

Tha Thong Lang, our goal was to enhance the residents' quality of water. In Baan Tha Lane, our goal was to provide an adequate amount of water to all residents. Our objectives were to characterize the problems with the water systems, evaluate the villagers' water uses and concerns with the systems, analyze the water quality, and create recommendations for the PDA. Our approach included conducting observations of the systems, surveying villagers, interviewing local authorities, performing water quality tests, and researching water treatment methods. This investigation led to recommendations and budgets regarding treatment systems and new infrastructure for the two villages' water systems. These recommendations serve to diminish the water quality and quantity problems in both communities and ultimately improve the standard of living for the Baan Tha Thong Lang and the Baan Tha Lane residents.

2. Background

This chapter discusses background information on Baan Tha Thong Lang and Baan Tha Lane, underground water sources in Krabi, factors that affect water quality and quantity, and finally treatment methods that could potentially address the water problems in the villages.

2.1 Overview of Villages

Our project focused on two coastal communities, Baan Tha Thong Lang and Baan Tha Lane, located in southern Thailand. Soon after the 2004 tsunami, the local government built well systems in both villages (Figure 2) because neither could afford to connect to the municipal water main. However, since the construction of the wells, the residents have encountered issues with their water systems and expressed their concerns to the PDA.

Baan Tha Thong Lang		Baan Tha Lane	
A1	Hua Kuan Tha Klang	B1	Chong Kao
A2	Sanam Geela		
A3	Sam Yak Klong Kruad		
A4	Klong Kruad		

Figure 2: Maps and names of wells in Baan Tha Thong Lang and Baan Tha Lane

2.1.1 Baan Tha Thong Lang

Located near the Andaman Sea, the village of Baan Tha Thong Lang consists of 361 households. Farming, vending and fishing are common occupations in the area

since the community has no noteworthy tourist attractions or hotels. The majority of its residents practice Islam.

As Figure 2 depicts, the villagers of Baan Tha Thong Lang receive their water from four wells of varying quality; Hua Kuan Tha Klang (A1), Sanam Geela (A2), Sam Yak Klong Kruad (A3), and Klong Kruad (A4). The majority of residents receive water from the well closest to their homes. Each well pumps the water from the ground and stores it in a water tower near the well location before distributing it to households. The water supplied from well A4 has high iron content as shown by the red water in Figure 3 and therefore utilizes a stone and sand filtration system to treat the water exiting the storage tank. Figure 4 shows the configuration for this water system. The three other wells have no form of treatment. (C. Choke, personal conversation, January 26, 2015).

Figure 3: Existing iron treatment tank of well A4 in Baan Tha Thong Lang

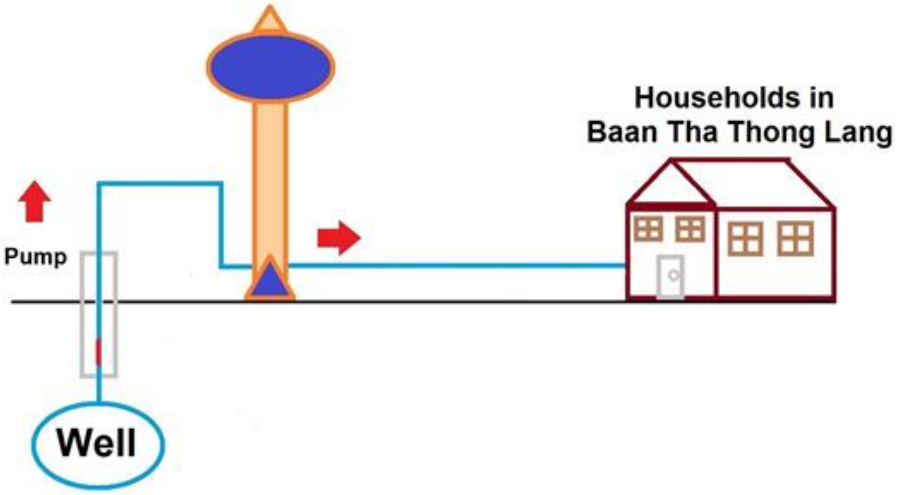

Figure 4: Diagram of Well A4 in Baan Tha Thong Lang

2.1.2 Baan Tha Lane

The community of Baan Tha Lane consists of 149 households and is located adjacent to the coast approximately 5 km west of Baan Tha Thong Lang. The principal source of income in Baan Tha Lane is the fishing industry. Most men in the village fish daily, although some farm or raise livestock. Most women are housewives or work as vendors in small stores. Some work in the nearby hotels and villas (S. Sanguansin, personal conversation, January 26, 2015). The village also has a small tourism industry stemming from a ferry landing used to explore nearby islands. A local kayak rental business, some small cafes, and a few hotels are popular among visitors. Despite these businesses, Baan Tha Lane is not a major tourist destination due to its remote location from popular Krabi cities.

As shown in Figure 5 below, two wells located 1.2 km from Baan Tha Lane supply water to the village. Figure 6 is a photograph of well B1 in Baan Chong Kao. These wells pump the water to two water towers that first supply 40 households in the

community of Baan Chong Kao. Afterwards, the leftover water flows further down to a large 100 m^3 storage tank. From the tank, the water supplies 100 households of Baan Kao Thong before finally arriving in Baan Tha Lane (S. Sanguansin, personal conversation, January 26, 2015). Because Baan Tha Lane is the last stop in the water distribution network, the water supply often runs low by the time it reaches the village.

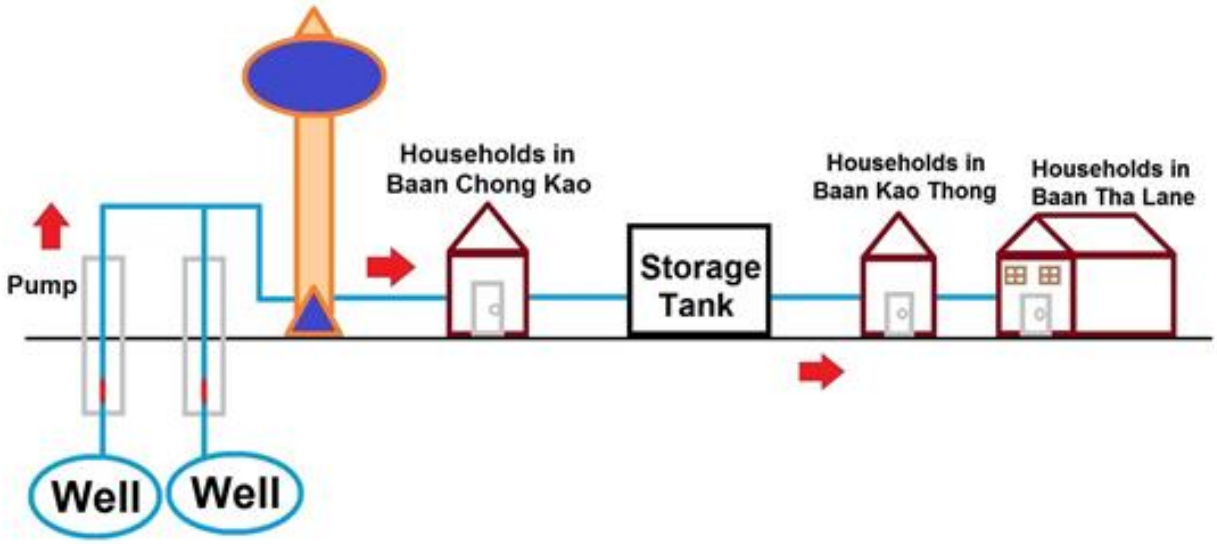

Figure 5: Water distribution system in Baan Tha Lane

Figure 6: Well B1 in Baan Tha Lane

2.2 Underground Water Sources in Krabi, Thailand

The majority of the people in Thailand receive their water from underground sources as is the case for Baan Tha Thong Lang and Baan Tha Lane. These communities draw from deposits of underground water through wells or aquifers, which are layers of water-bearing rocks. This porous rock is permeable, which allows excess rain to soak through the ground and replenish the aquifers periodically over time (Freedman, 2003). There are two common types of aquifers, unconfined and confined as Figure 7 depicts. An unconfined aquifer is closer to the surface and permeable rocks envelope it. A confined aquifer extends further below the surface from depths of roughly 60 meters and below. Less-permeable rocks surround these confined aquifers, which accounts for lower oxygen levels in the water. Metallic elements commonly found in confined aquifers are iron and manganese (Ahmad, 2012).

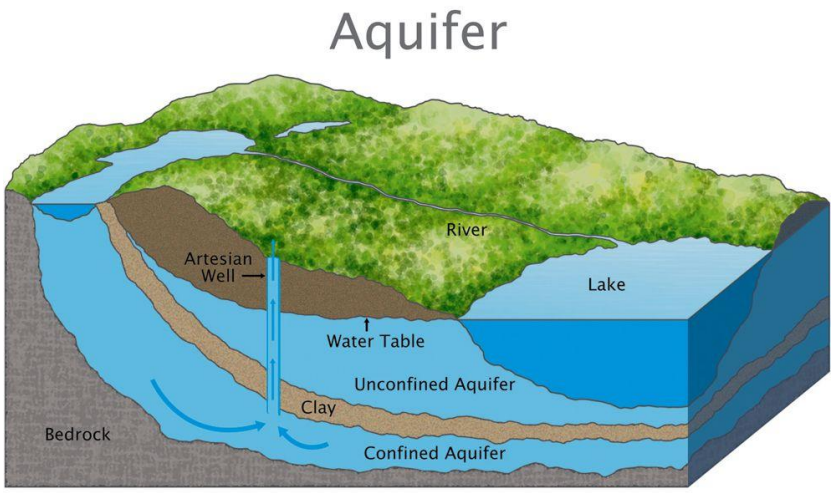

Figure 7: Unconfined and confined aquifers (Aquifer, n.d.)

2.3 Factors Affecting Water Quality

The minerals that form the rock lining of an aquifer affect the water quality of that source. Properties including hard water, alkalinity and iron are all commonly present in aquifers. These properties have the potential to damage infrastructure and in some cases cause human health issues.

2.3.1 Hard Water

Scientists define water hardness as a qualitative measure of the composition of several dissolved mineral ions, most commonly containing calcium and magnesium. Two types of hardness exist, temporary hardness and permanent hardness. Temporary hardness occurs when water content comprises of dissolved carbonate minerals; for example, calcium carbonate and magnesium bicarbonate dissociate to become Ca^{2+} and Mg^{2+}. Boiling the water is a method to remove this hardness. Conversely, permanent hardness comprises of dissolved calcium sulfate and is even more complex to remove.

Mineral ions that characterize hard water affect underground sources because they are present in the layers of sedimentary rocks that line the aquifer layer. These sedimentary rocks, such as limestone, can present high levels of polyvalent ions in the aquifers (World Health Organization, 1996). These minerals and ions are major concerns for water quality, as they can cause significant damage to water distribution systems by building up deposits that block water flow.

The effects of hard water also provide concerns for cleaning, sanitation, and drinking. Hard water can cause fabric to become stiff and rough, white fabrics to turn gray and a sour odor to develop. The hardness can also have an impact on hair, making it look dull and lifeless, and irritates skin. Moreover, the ions in hard water may react with heat, metallic plumbing and certain chemical substances, resulting in deficiency of home appliances.

Regardless of the various levels of water hardness, low, medium, or high, drinking hard water is usually not a major concern for human health (Kocak, 2011). For levels of low and medium hardness, taste is the biggest factor concerning water hardness. However, when the water hardness is high, large amounts of consumption may lead to cardiovascular disease, anencephaly, and cancer (World Health Organization, 1996).

2.3.2 Alkalinity

The Oxford Dictionary of Environment and Conservation defines alkalinity as the "capacity to neutralize an acid solution by its content of bicarbonates, carbonates, or hydroxides, adding carbon to the water and preventing the pH of the water from becoming too basic or too acidic, stabilizing it at a pH of around 7.0" (Oxford University Press, 2007). This definition indicates that alkalinity plays an important role in

sustaining water quality in the environment. This role as a buffer is the capability of water to sustain a healthy pH level by not becoming too acidic or basic. Water usually has an alkalinity range of about 10 to 500 mg/L. When we consider water to be high in alkalinity, its usefulness diminishes and it will exhibit harmful qualities. Dissolved alkaline compounds remove protons from water, thus making the pH of water become higher due to a lower concentration of protons. Common causes of pH changes are rock linings, soils, salts, and household chemicals.

Water that is high in alkalinity exhibits traits that are potentially destructive for a water network environment. When dissolved in water, alkaline compounds cause the water to feel slippery and have a bitter taste. The impact of the coastal water plays a significant part in causing groundwater to contain high amounts of alkalinity. As with the characteristics of hard water, the exchanging ions affect water high in alkalinity. Oak-Bae Kim and Hee-Youl Park's analysis of seawater intrusion determined that the hydrate, sulfate, and calcium ions found in fresh groundwater sources contain the same charge as sodium and chloride ions found in seawater (Kim & Park, 1998). This study suggests that seawater intrusion can contribute to producing water characterized as high in alkalinity.

2.3.3 Iron Content

High iron concentration is one of the most common problems associated with the quality of groundwater (Sharma, 2001). As water passes through layers of rock in the earth, minerals such as iron will dissolve into the water. The longer the water is underground and flowing through cracks in the rock, the more iron it will accumulate ("Iron Problems", 2002). This means that water found deeper in the earth is more likely

to have higher concentrations of iron. Iron pipes may also increase iron deposits in water (Sharma, 2001).

Other water properties such as pH and alkalinity can affect the concentration and type of iron found in water. The pH of water can determine how many valence electrons the dissolved ions of iron have. Most water ranges from a pH level of 5.0 to 8.5, meaning that the iron found in these sources of water is divalent, iron (II), so long as it does not come in contact with electron acceptors like oxygen. Water in underground sources, like aquifers, has less access to oxygen; therefore, the dissolved iron is divalent. Additionally, water with high alkalinity will often have lower iron content.

High amounts of iron precipitates can produce red, brown, or yellow stains on items such as faucets and laundry. Iron-rich water may also present discoloration and a bitter taste. Additionally, iron can promote the growth of microorganisms. This growth can result in deposits of minerals and organic slime building up within pipes, causing clogs and inefficiencies in water distribution networks (Sharma, 2001). Although high iron content in water creates a variety of problems, it poses minimal threat to human health. The World Health Organization believes that iron concentrations of even 2 mg/L of water do not present health hazards, and the US Environmental Protection Agency does not view elevated levels of iron in drinking water as a health concern (WHO, 1996; "Iron Problems", 2002).

2.3.4 Additional Factors

There are several other factors that play a role in affecting water quality. Salinity, manganese, copper, zinc, sulfate, chloride, fluoride and nitrate are common properties that can be detrimental to water systems. Among the most common for groundwater sources are salinity and manganese.

Salinity is the measure of dissolved salt in water. Groundwater deposits become salty as ions dissolved in water pass through soil and rock. Deposits near bodies of salt water such as the ocean will have higher amounts of salt (Singh & Wallender, 2011). Water high in salinity can be unhealthy to consume and can corrode water distribution systems. On the other hand, manganese in underground water contains Mn^{2+} and Mn^{3+} ions. The solid form of manganese can deposit and precipitate as black particles and block pipes. High concentrations of manganese cause unpleasant taste as well.

2.4 Factors Affecting Water Scarcity

The definition of water scarcity is the physical, measurable lack of water supply in relation to human necessity (Schulte, 2014). Many factors are responsible for this lack of water including environmental and socioeconomic causes.

2.4.1 Environmental Factors

Weather patterns, climate, and different types of water sources affect the quantity of water present in any region. Thailand has a monsoon climate which contributes to rainy and dry seasons. During the dry season, November to May, the country receives significantly less rain as seen in Figure 8 below. During this period water sources including aquifers can lose significant volumes of water. Therefore, this monsoon climate often creates water scarcity issues (Rijsberman, 2006). However, confined aquifers retain a greater amount of water during this season because they are deeper underground.

Geographic location also plays a role in water scarcity. Seawater intrusion can limit freshwater supplies to communities along the sea. Any wells dug near the ocean run the risk of being too salty for human consumption.

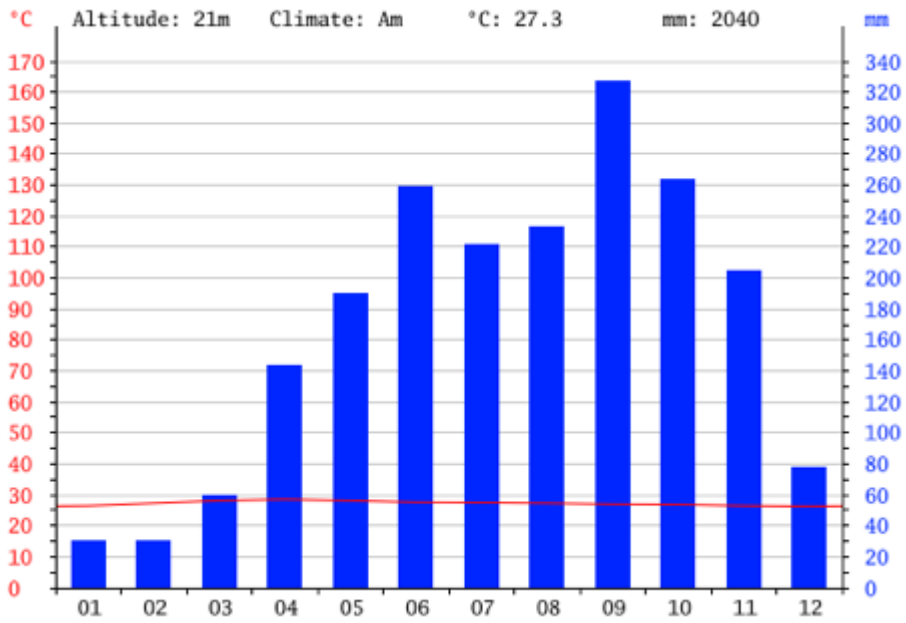

Figure 8: Average monthly rainfall for Krabi province (Climate: Krabi. (n.d.)

2.4.2 Socioeconomic Factors

In addition to the environment, social and economic factors influence water scarcity. People require thousands of gallons of water every day to grow and process food and clothing materials (Armstrong, 1971). This vast per capita water consumption can put a strain on regions already experiencing limited water supplies. Tourism also requires more water to operate restaurants and hotels. Moreover, income inequality plays a role in water scarcity as wealthier individuals can afford to pay for more water than poorer neighbors.

2.5 Feasible Treatment Methods for Water Quality

This section introduces different methods for treating water contaminants including hardness and iron. Each subsection defines a single water treatment method, describes how the method works, and identifies the respective pros and cons.

2.5.1 Chemical Precipitation

One method that treats water hardness is chemical precipitation. This method involves the addition of chemicals to remove heavy metals, known as inorganic impurities. Different chemicals activate similarly but remove the heavy metals according to their reactivity. Carbonate precipitation is a specific type of chemical precipitation that can reduce the hardness in water. Since hard water has high levels of calcium and magnesium, this treatment method removes these elements, which softens the water and makes it safer to utilize. Carbonates combine with dissolved calcium and magnesium in the water to produce the insoluble compounds of calcium and magnesium carbonate. For this procedure, the operator adds a slight amount of chemical to the water in the storage tank, then leaves it to settle for the heavy metals to precipitate. The solids then gather at the bottom of the storage tank and the operator must remove them regularly to keep the system well maintained and clean.

The benefits of chemical precipitation are the simplicity of its operation and efficiency at water softening. Individuals without expertise in water treatments can operate this method. Purification by chemical precipitation is very effective, especially in a small-scale scenario such as rural villages. In terms of chemical waste, the large precipitates produced are non-toxic residue (ITRC, 2010).

Chemical precipitation does have some flaws. This method has high installation costs and the maintenance costs depend on the amount of sludge disposed, reagent used, etc. Furthermore, this treatment method is only effective for specific minerals that cause water hardness (ITRC, 2010).

The cost for installing the chemical precipitation treatment ranges from **150,000 to 190,000 Baht** depending on labor and materials costs. Appendix N provides a more extensive budget analysis for this system.

2.5.2 Ion Exchange

Ion exchange is another method for treating water hardness. It operates by passing water through a polymer in the form of a resin, which contains pockets of ions. Depending on the type of resin used, certain ions dissolved in the water substitute for the ions within the resin. For example, sodium or potassium ions can substitute calcium and magnesium ions ("Filtration Facts", 2005). Eventually, the substituted ions within the resin deplete, and regenerate with new substitution ions. To perform regeneration, the pump backwashes the ion exchange device by drawing water saturated with substituted ions through the resin in the opposite direction of normal flow. This process also removes any fine particles trapped in the resin ("Ion Exchange", 2009).

A major advantage with ion exchange is that it has a relatively inexpensive initial capital investment. The procedure for this treatment is simple and requires a limited amount of machinery.

Some disadvantages are that the deionization beads can leave behind particles and contaminants in the water. It also has high operation costs and requires the acquisition of specialized chemicals, which may pose difficulties for those in isolated areas. However, the quantity of resin depends on the size of the community. In addition, the backwashing process of the system creates brine. This waste water demands some form of recycling or disposal and dumping it poses environmental problems ("Ion Exchange", 2009).

The cost for implementing an ion exchange system is between **135,000 to 165,000 Baht**. Appendix O gives the itemization of these estimated implementation costs.

2.5.3 Manganese Greensand Filtration

Manganese greensand filtration is a common treatment method due to its high efficiency at removing iron and ability to perform at high flow rates (Iron and Manganese Removal, 2014). This method operates by forming an active manganese oxide coating by utilizing the ion exchange properties of the modular grains of the greensand. This coating has the capacity to remove iron and manganese due to chemical oxidation reduction reactions (Zabel, 2010). At the end of the process, the coating removes the excessive iron from the water.

This treatment method also presents various benefits including no concentration of chlorine, no sulfur dioxide, no increase of total dissolved solids, no backwash, etc. (Hungerford & Terry, 2003). The biggest disadvantage with manganese greensand filtration is that it requires consistent replenishment with a chlorine or permanganate solution.

According to the Managing Director of 4Tech Company, the total cost for this treatment is approximately **90,000 Baht per 10 m^3 tank**.

2.5.4 FCU-8 Softener Water Filtration System

The FCU-8 Softener Water Filtration System is a machine designed to bring water to drinking quality standards, especially in rural regions. It operates by flowing water through a series of five steps as shown in Table 2 below. Upon flowing through the

entire machine, the water is safe enough for consumption without any additional treatment.

Table 2: Purpose for each FCU-8 machine component

Component	Purpose
Anthracite filter	Removes iron and manganese, decolors
Softener	Removes limestone, cadmium, sulfate magnesium
Activated carbon filter	Removes organic material, dechlorinates, decolors
Ceramic filters	Removes microbe particles
Ultraviolet	Kills viruses and bacteria

The FCU-8 machine has many advantages; most notably that it treats a variety of organic and inorganic contaminants all together with one system. In addition, it has a relatively inexpensive installation cost, works at a high capacity of 900 L/hr, and operates successfully around the world.

The only disadvantage with the system is its complex and relatively expensive maintenance schedule. Each component requires cleaning/replacing at different intervals of time and through different procedures. The maintenance does not require an expert but does need an accurate method of keeping track of what parts need cleaning and how frequently that needs to happen.

The cost of installing an FCU-8 system is **58,000 Baht**, not including any extra storage tanks, labor, or pipes for the installation. Appendix S gives the complete details about this system.

2.6 Background Summary

In summary, the communities of Baan Tha Thong Lang and Baan Tha Lane in Krabi province are currently using water network systems that the local government constructed after the tsunami in 2004. These systems receive water from an aquifer deep beneath the ground.

The most pressing issues between the two communities are water quality and water scarcity. Many treatment methods including chemical precipitation, ion exchange, and manganese greensand filtration effectively treat common contaminants in aquifer water such as hardness and high iron contents. The FCU-8 machine treats a variety of contaminants to drinkable quality.

The causes for water scarcity are primarily environmental or socioeconomic. Combating water quantity is more complicated than water quality as it involves finding new sources of water or addressing complex social issues. We kept into consideration all of this background information when executing our methodology and eventually devising recommendations for our sponsor.

3. Methodology

Our goal for this project was to aid the villages of Baan Tha Thong Lang and Baan Tha Lane in Krabi to improve their current water systems. To achieve this goal, we accomplished four objectives. First, characterize the issues with the water distribution systems; second, evaluate the villagers' uses and concerns with the systems; third, analyze the current water quality delivered by these systems; and fourth, develop a set of recommendations for the PDA. The information we gained from objectives one to three allowed us to complete our fourth objective. Figure 9 illustrates our methodology process.

We completed this project over an eight week period at Chulalongkorn University in Bangkok and by taking a three day assessment trip to the villages in Krabi during the third week of our project. This chapter outlines our approach to accomplishing our four objectives.

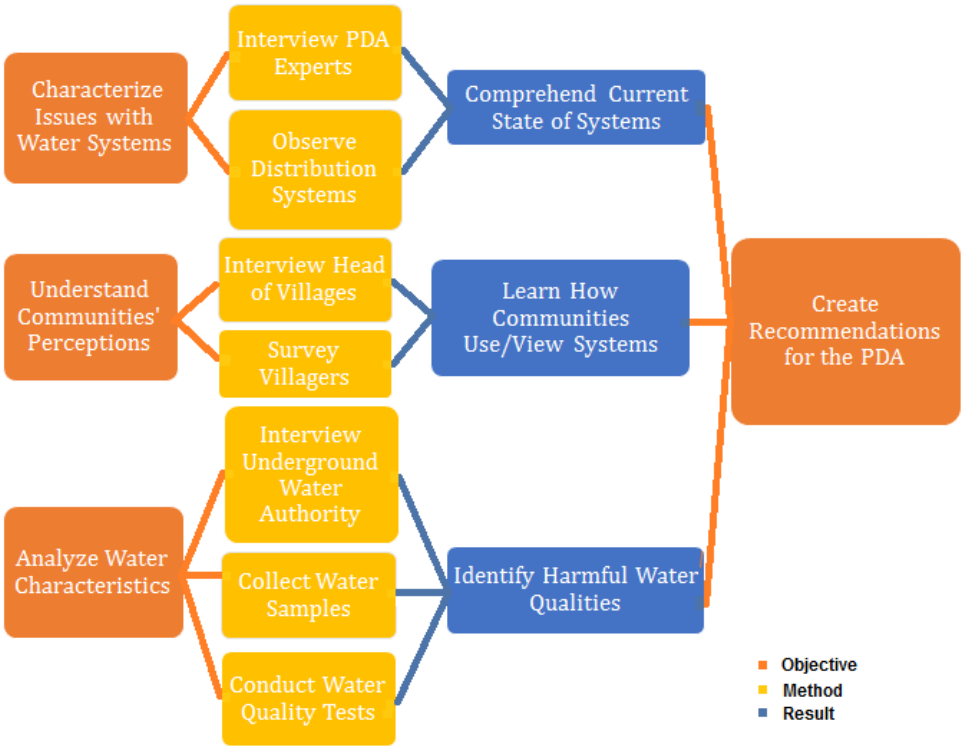

Figure 9: Methodology diagram

3.1 Characterize the Problems with the Current Water Systems

Our first objective was to characterize the problems with the water distribution systems of Baan Tha Thong Lang and Baan Tha Lane. Due to their remote locations and small population size, our team had minimal background information on the villages. Therefore, we completed two tasks during our assessment trip to Krabi to accomplish the first objective.

The initial task was to observe the water distribution systems of the two villages. The team broke into two groups of four students, with two WPI students and two BSAC students per group. One group observed the system of Baan Tha Thong Lang while the other observed the system of Baan Tha Lane. Representatives from the Krabi PDA introduced us to residents of both villages who were familiar with the systems' layout and operation and guided us through the villages.

The students who focused on Baan Tha Thong Lang inspected the four wells that distributed water to the community. At each location, the group recorded the geographic positions of the wells and tanks, took pictures, made diagrams of the layout of the four wells, and noted any corrosion or leaks of visible pipes and pumps. The Background chapter contains a map of the location of the wells and layout of the water distribution systems.

Similarly, the other group of students investigated the government-built wells in Baan Tha Lane with the guidance of local residents. They also recorded the geographic locations, took pictures, made diagrams, and noted pertinent leaks or corrosion in the system.

The second task was to conduct an interview with Khun Aumnuay, the director of the PDA in Krabi. This interview gauged the PDA’s expectations for our project. Originally, the team thought that both villages were dealing with similar water quality issues and

only one of the villages experienced water scarcity during the dry season. Here, we learned that Baan Tha Thong Lang had only reported problems with water quality, while Baan Tha Lane had reported problems with chronic water scarcity. We also found that the villagers of Baan Tha Lane may not be willing to have an improved water system, as they would not want to pay for it. In addition, the hotels located in the village may have been obtaining a substantial amount of water, depleting the villagers' water supply. We then decided to divide our project into two parts, as our team would need to develop separate solutions for each village. Appendix H contains the full transcript of the interview with Khun Aumnuay.

3.2 Evaluate the Villagers' Uses and Concerns with the Systems

Our team conducted surveys in both villages to fulfill our second objective. We created these surveys to identify damage to infrastructure, complaints, and health issues voiced by the consumers of the water systems. Our team tailored two sets of surveys to cover the complications the villagers of Baan Tha Thong Lang and Baan Tha Lane faced with water quality and water scarcity respectively. We decided to use surveys as opposed to interviews because they allowed us to collect both qualitative and quantitative. The surveys included questions containing a predetermined list of answers the villagers could select quickly, such as age and gender. Other questions were open-ended and allowed villagers to give detailed responses with their opinions, to ensure that we collected as much information as possible. To conduct the surveys, our team split into the same groups that performed the observation of the systems. The interview groups consisted of two pairs of two students per village, with one WPI student and one BSAC student per pair.

In Baan Tha Thong Lang, there were 330 households that used the water system. The other 31 households in the community received their water from other sources. We did not survey representatives from this second set of households to ensure that our responses were pertinent to our goal of improving the well water system. The surveys included questions to identify the water quality issues and demographics of the community. These surveys asked residents; what purposes they used the water for, such as drinking, household use, or sanitation; whether they thought the water was safe for any of these uses; if the quality of water had caused them harm; and other such questions related to the water system. The teams working in this village conducted 21 surveys in total. There was no common market or gathering place in Baan Tha Thong Lang, so we conducted these surveys door to door, asking residents individually if they would participate in our brief survey. We made sure to collect surveys from a range of households that used each of the four wells, to ensure our data was accurate for the entire community. To save time, the BSAC students conducted and recorded the surveys in Thai. The WPI students recorded the conversations using a phone, while noting any additional observations. Appendix C1 contains the complete survey with a translated Thai version in C2.

In Baan Tha Lane, there were only 149 households and, similarly to Baan Tha Thong Lang, there was no common market or park that naturally lent itself to conducting surveys. For this reason, we allowed the assistant head of the village to bring us to private residences where we carried out the surveys. These surveys included questions to identify water scarcity issues and demographics of the community. Some questions included how long these residents had been experiencing water shortages, how frequent were the shortages, and what did the residents think were the causes of these shortages. Overall, we conducted 16 surveys. When performing these surveys, the

BSAC students spoke in Thai and translated the responses to each question into English for the WPI student to record. Unlike the procedure in Baan Tha Thong Lang, this process eliminated translating the responses in Bangkok later on, and sped up the analysis process. Appendix D1 contains the complete survey with a translated Thai version in D2.

In addition to surveying the residents of both villages, we conducted an interview with the assistant to the village head of Baan Tha Lane, Khun Suchart Sanguansin. We were unable to interview the leader of Baan Tha Thong Lang as he was away on business during our trip. The purpose of the interview with Khun Suchart was to understand the culture and demographics of the communities from the perspective of an authority figure, and acquire knowledge on the willingness of the villagers to receive help from external organizations. Appendices B1 and B2 contain the list of interview questions and responses.

To organize the survey data, the BSAC students that visited Baan Tha Thong Lang transcribed the surveys into English once we were back in Bangkok, as the Baan Tha Lane team had already done during the assessment trip. We input the quantitative responses from both villages into a spreadsheet to allow our team to create items such as frequency charts of the data. We transcribed the qualitative responses into a spreadsheet as well. We color coded similar qualitative responses to create a visual representation of the most common concerns the villagers expressed in the surveys.

3.3 Analyze Water Quality

Our third objective was to analyze the composition of the water supplied to the villages. We completed four tasks as part of this objective. The first task was to create a specific list of testing parameters for the water, the second task was to learn the

procedure for collecting the water samples and to purchase the necessary materials, the third was to collect the samples from the wells in Baan Tha Thong Lang and Baan Tha Lane and perform pH tests, and the fourth was to test the water at Chulalongkorn University.

We aimed to improve the villages' water quality for non-drinking purposes, such as washing clothes, cleaning dishes, and personal hygiene. Therefore, we decided to perform only the tests necessary to deem the water safe for all these purposes. To create our list of testing parameters, our team consulted three sources. The first source was the set of acceptable water standards given by the Krabi Department of Groundwater Resources (Appendix A). This document outlined important water properties to test for, as well as "Acceptable" and "Maximum" levels for each property. The second sources were the oceanography professor Penjai Sompongchaiyakul and Dr. Luxsana Dubas of Chulalongkorn University. Both of these experts had backgrounds in water research and testing. The third source was a set of water test results conducted by the T-Tech Water Treatment Company at the wells in the Baan Tha Thong Lang and Baan Tha Lane on November 15, 2014. The PDA hired T-Tech to perform tests for various parameters, and gave us the results of their tests (Appendix G). From the testing parameters we created, we compared our findings with T-Tech's findings to determine if there were any differences in water property levels. The water parameters we tested for are in Appendix F.

The second task was to learn the procedures for water sample collection and to purchase the necessary materials for these tests. Our team worked with the Food Research and Testing Laboratory of the Science Faculty at Chulalongkorn University to gain this information. The laboratory technicians explained how to conduct the tests and gave us an index of the supplies needed. The lab technicians also informed us that

we had to perform pH testing on-site, and provided us with two pH meters along with a bottle of electrolyte solution to clean the instrument after performing each test. We needed to collect 3.5 L of water per well for all tests. The testing for heavy metals needed 0.5 L per sample and required us to add nitric acid after we collected the sample. We had to store these samples in polypropylene bottles. In total, we procured ten 0.5 L polypropylene bottles along with two foam boxes to transport the samples from the villages back to the University. Once in Krabi, the team purchased 12 additional commercial bottles to hold the volumes of water that did not need special containment. According to the Department of Groundwater Resources, commercial polyethylene bottles could collect and store water samples not requiring nitric acid.

The third task was to perform pH tests as shown in Figure 10 and collect the water samples. Going to all five wells in both villages, we conducted two pH tests per well, and recorded the results for analysis in Bangkok. For collecting water samples, our team divided into four pairs in Baan Tha Thong Lang. Each pair traveled to one of the four wells. In Baan Tha Lane, the entire team visited the one well to collect the samples. The procedures for the pH tests and sample collection are located in Appendix T.

Figure 10: Finding pH levels with a pH meter

Our last task was to deliver the water samples to the Food Research and Testing Laboratory to perform the tests. To do this, we preserved the samples in ice to ensure they remained at 4^0C throughout the entire trip. Our team transported the samples by airplane but since ice is a banned substance, we had to remove the ice from the containers, sealing them with tape and "Fragile" labels. Approximately two and a half hours after checking the samples on the plane, we placed the nitric acid in the required sample bottles and preserved them in ice again. The procedure for placing the acid in water is in Appendix T.

The team delivered the samples to the Food Research and Testing Laboratory 18 hours after collection. The test results took two weeks to complete. After performing the tasks mentioned above, we used all the data from the water testing results to complete our final objective of creating recommendations for the PDA.

3.4 Create Recommendations for the PDA

Our recommendations were a result of the information we acquired from our observations of the water systems, interviews with the PDA employees and assistant head of the village, surveys of residents of the communities, and water quality testing. Our team utilized three steps to create a list of recommendations. The first step was to analyze the survey and interview data, the second was to evaluate the testing results from the Food Research and Testing Laboratory, and the third step was to create budgets for the recommended improvements.

We analyzed the survey responses from the villagers by first inputting the data into an Excel spreadsheet. Our team processed the categorized information to group together opinions based on demographics, uses for water and access to well water. Due to the small sample sizes and types of questions we asked, we were unable to use

statistical analysis software. Using comparison t-tests would have required sample sizes of at least 20, which we did not have for any of the wells in Baan Tha Thong Lang or the well in Baan Tha Lane. Instead, we decided to analyze the data by creating frequency distribution tables; e.g. 3 villagers from our surveys at well A3 identified themselves as being between the ages of 25-34. Our team then analyzed the qualitative data by color coding the responses of the open-ended questions and categorized matching opinions and concerns. We used this type of coding to create a statistical visualization to depict the specific concerns of the villagers. The final task in this step was to combine the qualitative data and quantitative data to interpret the types of concerns that were most prevalent. The analysis of this step is in the Results and Analysis chapter.

The second step was to evaluate the water test results. This step ensured that our recommendations addressed the detrimental water properties from our well samples. Our team compared the results from the Food Research and Testing Laboratory tests with both the Department of Groundwater Resources tables and the T-Tech results from 2014.

The final step was to create a budget for our proposed recommendations. To do so, we researched existing reports with costs of similar solutions implemented in other villages in Krabi. We also held conversations with the authors of these reports and officers of the Department of Groundwater Resources to create a reliable range of prices in our cost estimates.

In summary, as part of our methodology we collected the majority of the information through an assessment trip to Krabi. During this assessment trip, we interviewed villagers familiar with the systems, the assistant head of the village of Baan Tha Lane, and the director of the PDA office in Krabi; surveyed the residents of the two villages; performed pH testing; and collected water samples for testing at

Chulalongkorn University. We analyzed our data by evaluating the survey and interview responses with frequency charts and color coding techniques. From these steps, we devised solutions while taking into account costs and feasibility.

4. Results and Analysis

The completion of each objective led us to compile results about the most important concerns with the systems' infrastructure, complaints of the villagers, and properties of the water. We list our most relevant results, which provided the necessary information for developing our recommendations. This chapter presents our results and analysis for each objective of our methodology.

4.1 Water System Characteristics

As mentioned in the Background chapter, Baan Tha Thong Lang received its water from four different wells. The PDA provided us with detailed information from each well presented in Table 3, including depth, flow rate, and number of households receiving water from each well.

Table 3: Baan Tha Thong Lang well specifications

Well	Depth (m)	Flow Rate (m^3/hr)	Households
(A1) Sanam Geela	33	8	68
(A2) Hua Kuan Tha Klang	43	10	120
(A3) Sam Yak Klong Kruad	28	5	35
(A4) Klong Kruad	110	24	107

During the physical examination of the wells, our team found that only well A4, Klong Kruad, possessed an iron removal system. As explained in the Background chapter, this is likely due to the fact that well A4 is over 60 m deep and draws its water

from a confined aquifer. The iron removal system filtered iron out in the form of a reddish-brown liquid, which the villagers flushed once per month. They cleaned the system approximately once every two weeks. We also found no major damage to any of the visible parts of the systems, other than some minor rusting in pipes. These findings differed from our expectations since, from our initial research, we anticipated the presence of leaks and corrosion in some infrastructure due to hardness and alkalinity. These observations meant we did not have to address damage to pipes, pumps, or tanks in our recommendations.

In Baan Tha Lane, we observed that the two wells appeared to be working successfully without infrastructural damage. We were unable to gather data about the depth of the wells, flow rates, or exact number of households that used the wells. However, we learned from Khun Suchart the complete path of the water distribution system from the aquifer to Baan Tha Lane (Figure 5 in Background).

4.2 Perceptions of Village Residents

In the following subsections, we present graphs as well as analysis of our interviews and survey responses. Afterwards, we summarize the most relevant outcomes of these methods.

4.2.1 Analysis of Survey Results in Baan Tha Thong Lang

Table 4: Baan Tha Thong Lang survey percentages

Baan Tha Thong Lang Well	Number of Households Surveyed	Total Number of Households	Percentage of Well Users Represented
(A1) Hua Kuan Tha Klang	4	68	5.9%
(A2) Sanam Geela	5	120	4.2%
(A3) Sam Yak Klong Kruad	6	35	17%
(A4) Klong Kruad	6	107	5.6%

Table 4 shows the breakdown of the villagers we surveyed from each well in Baan Tha Thong Lang. Despite the fact that we only surveyed a small percentage of well users, we did manage to obtain a similar number of responses for each well.

We wanted to identify the villagers' concerns regarding water consumption. Through our conversations with the PDA, we anticipated that not all of the villagers consumed water from the wells. From our surveys we learned that 19 of the 21 residents (90%) did not believe the well water was fit for consumption. 4 people (19%) in our sample population consumed the water without filtration. 2 of these 4 residents informed us they could not afford to purchase water from another source, so they had to drink water straight from the system. 3 of the residents (14%) used some form of in-home filtration to treat the well water before they consumed it, and 14 of these residents (67%) purchased 20L containers of drinking water from vendors at a price of 12 Baht per container. Therefore, our assumptions were correct in that a slight majority of Baan Tha Thong Lang residents received drinking water from a separate source than the wells. Figure 11 provides the full set of results for these questions. The label "vendor" in our charts indicates a commercial source of drinking water, e.g. bottled water.

Multiple residents using well A4 reported that their water occasionally contained red precipitates consistent with high iron concentration. Because well A4 already had an iron treatment system, this raised some questions among our team as to whether or not the treatment was working properly or needed to be better maintained.

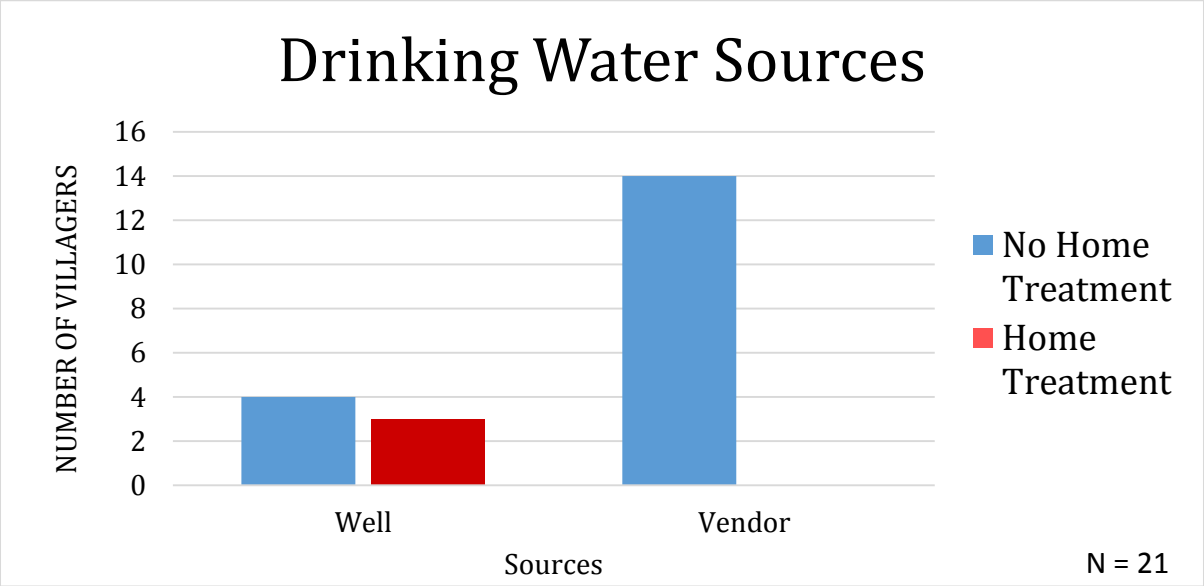

Figure 11: Drinking water sources in Baan Tha Thong Lang

When we asked about cleaning and sanitation, all 21 residents surveyed thought the well water was safe for these purposes, including cleaning clothes, washing dishes, and personal hygiene. When determining if water quality for agricultural uses was a concern, we found that only 8 of the villagers (38%) reported that they used the well water for their home gardens. This question helped confirm that agriculture was not a major source of income, as it is in the surrounding parts of Krabi. Overall, these responses show that the community members felt comfortable using the well water for these non-drinking purposes. We were able to determine from the data that the only water the residents bought from vendors was for drinking, and they did not need to spend additional money buying water for household purposes.

In addition to water uses, our team asked residents to identify the type of damages they had experienced with their network infrastructure as a result of poor water quality such as corrosion, mineral buildup, or leaks. Of the 21 people surveyed, 8 (38%) reported pipe or pump damage without identifying the cause. We received 6

(29%) reports of a particular incident one year before involving construction equipment that ran over a pipe and caused damage. The final 7 villagers surveyed (33%) said that they had not experienced any such damages. None of the residents reported corrosion or mineral build up in personal property that they believed was a result of the water quality. These responses imply that the majority of residents do not believe the quality of water causes damage to infrastructure. We were surprised to learn that the water was not corroding personal appliances such as toilets, showers and sinks, as we originally anticipated. From this information, our team learned that we would not have to recommend any replacements for pipes or pumps.

Our team evaluated the villagers' general satisfaction with the wells and their thoughts about any needed improvements. 16 of the villagers (76%) reported that they were satisfied with the current system, whereas 5 villagers (24%) were dissatisfied because it did not provide drinking water. However, 18 (86%) of them expressed interest in improving the water quality to drinkable standards in every well. Figure 12 illustrates these responses. These data heavily imply that the majority of people in this community desire drinking water from their wells so that they do not have to continue paying for separate water.

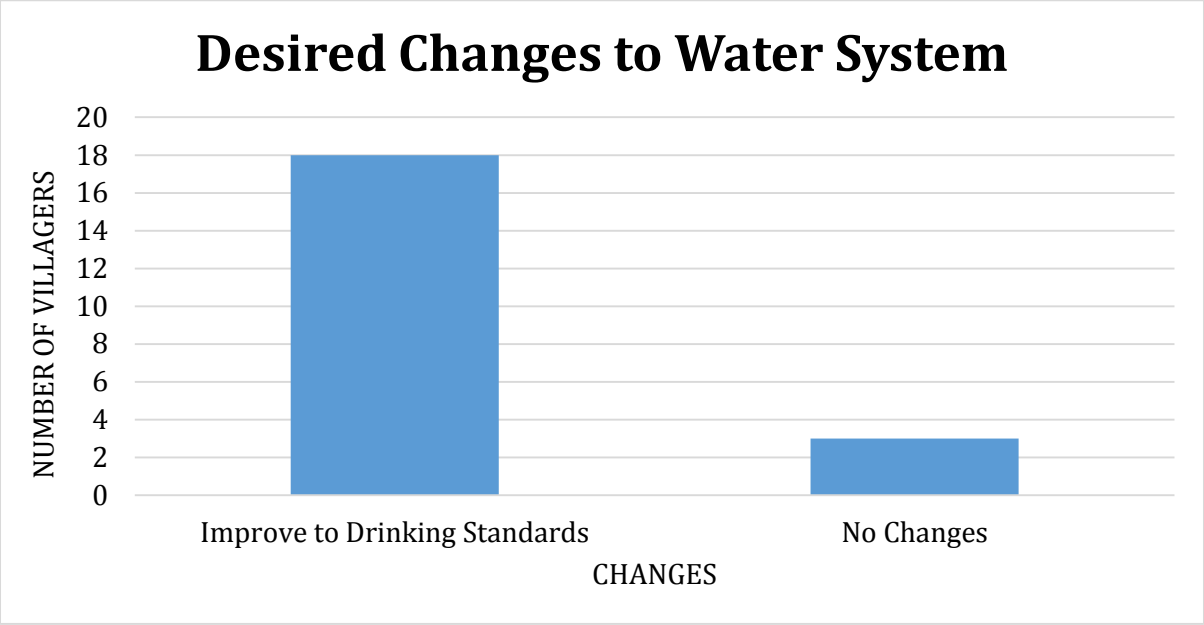

Figure 12: Desired changes to water system in Baan Tha Thong Lang

4.2.2 Analysis of Survey Results in Baan Tha Lane

Based on our background research, our team understood that environmental factors, including seasonal weather patterns, can be a cause of water scarcity. This information led us to ask the residents of Baan Tha Lane how the seasons related to their water supply. Of the 16 villagers we surveyed, 13 (81%) stated they did not have enough water throughout the entire year as shown in Figure 13. One of these villagers informed us that she had not received water for one month. The remaining 3 villagers (19%) lacked water only in the dry season. Thailand's wet and dry seasons appear to have minimal effect on the quantity of water in the village. Instead we realized that the lack of water was constant and that some aspect of the water system was likely the cause of the scarcity.

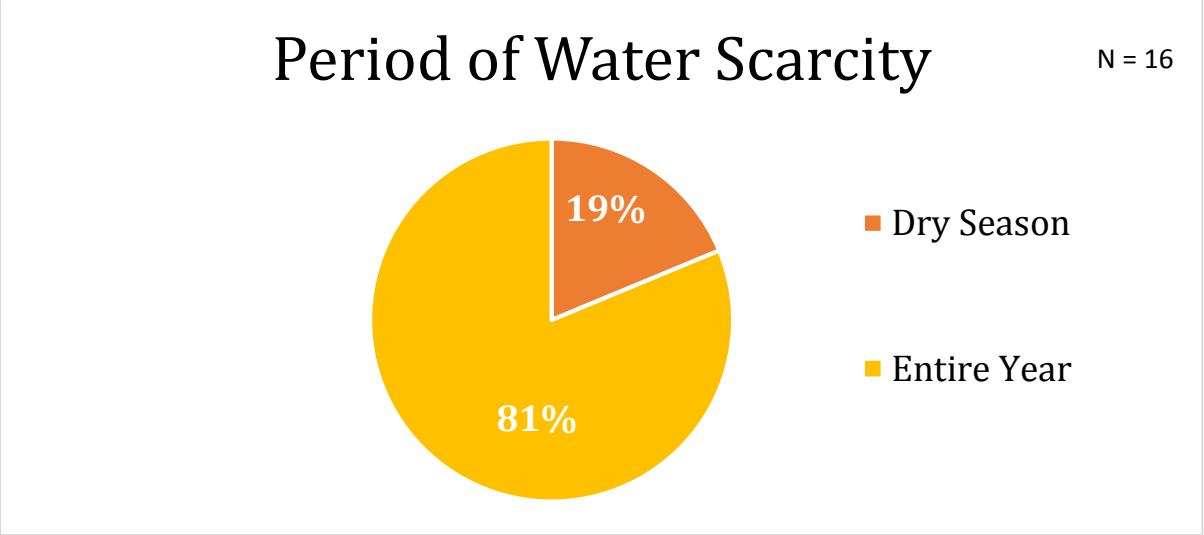

Figure 13: Period of water scarcity in Baan Tha Lane

Based on information we learned from Khun Aumnuay, we were under the impression that hotels in Baan Tha Lane may have been partly responsible for the water scarcity. 9 of the villagers we surveyed (56%) did not believe hotels were a cause of this problem. 2 (13%) mentioned that the problem existed before the hotels came to Baan Tha Lane. Surprisingly, only 5 of the villagers (31%) thought hotels were the main cause for the water scarcity (see Figure 14). Therefore, the data suggest that the hotels are most likely not responsible for water scarcity.

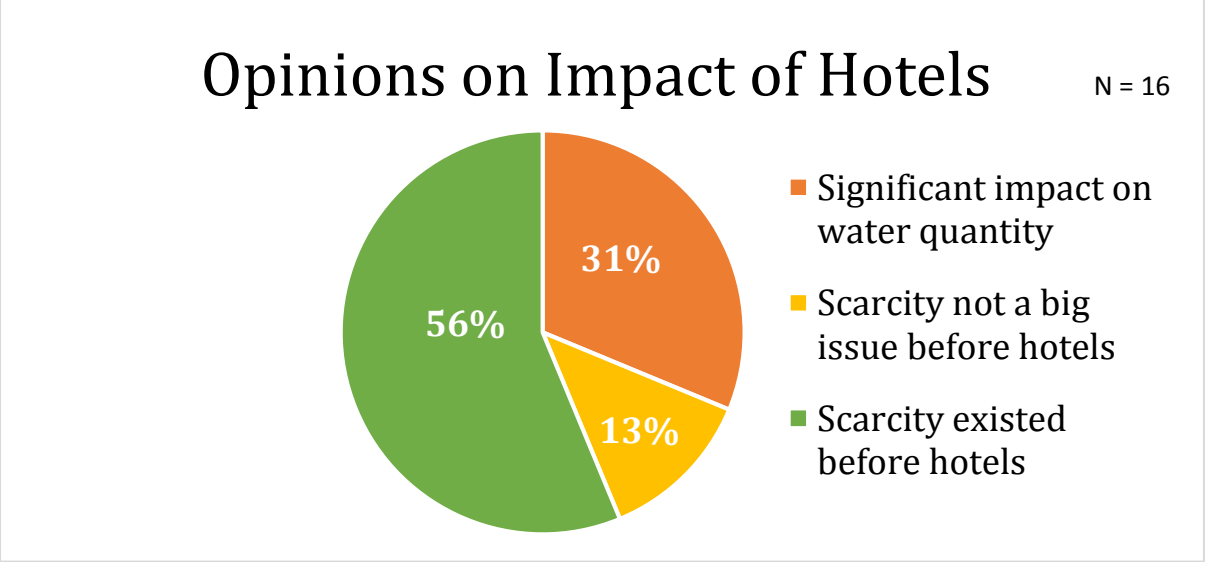

Figure 14: Opinions on impact of hotels in Baan Tha Lane

We also sought to gauge whether water quality was an issue because well B1 is located less than 3km from the wells of Baan Tha Thong Lang. Our team asked the residents of Baan Tha Lane about how they felt about their water properties. Our survey responses showed that 14 of the 16 residents (88%) stated they did not use the water for drinking purposes, as they considered it unsafe for consumption. These individuals either bought drinking water commercially or used the water from their own shallow backyard wells. None of the residents reported any sicknesses they believed the well water caused, most likely due to the fact that almost all of them did not drink or cook with this water. Figure 15 summarizes the results on drinking water sources.

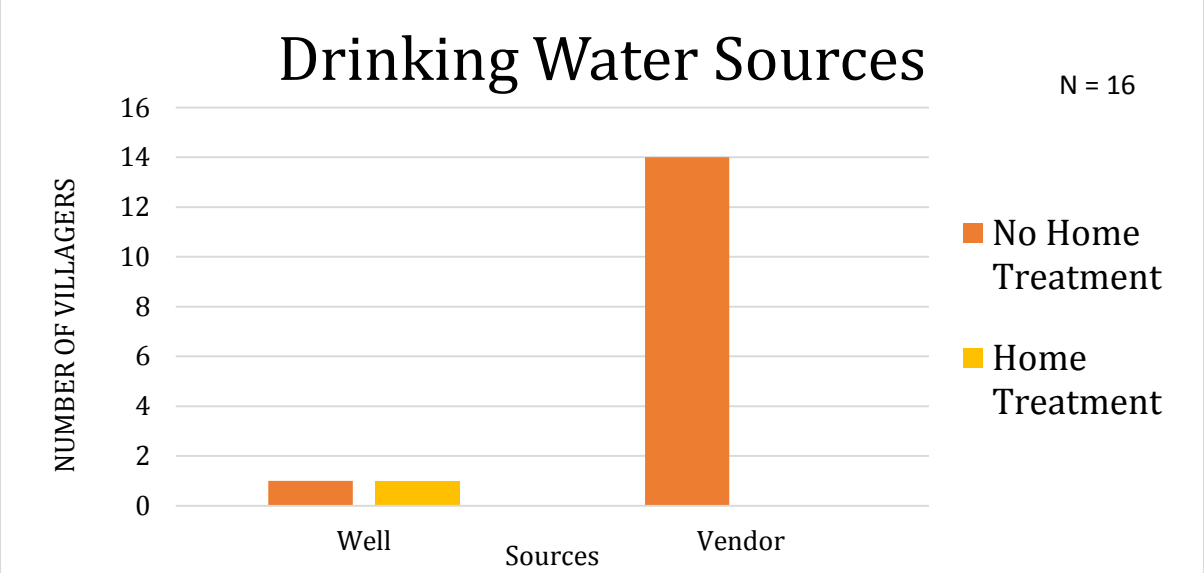

Figure 15: Drinking water sources in Baan Tha Lane

In addition, we wanted to comprehend the villagers' non-drinking uses of the well water. We found that all of the villagers used the water for household purposes such as cleaning clothes, washing dishes, and watering plants. For sanitation, 15 residents (94%) used the water without any treatment. 10 of the residents (63%) used the well water for home gardens without any complaints. These responses were also

quite similar to those from Baan Tha Thong Lang and overall suggest that the water quality caused no problems for non-drinking purposes.

We anticipated that the villagers were also facing leaks and corrosion in their pipes, taps, showers, toilets, etc. The surveys showed that 10 of the 16 villagers (63%) did not face any issues with home appliances. Out of the 6 villagers (37%) who reported problems with the system, only 1 person mentioned that some public pipes had leaks and corrosion caused by poor quality water. The rest cited human error as the source of the damage. These survey responses led us to believe that the water quality is not responsible for damaging infrastructure. This result corresponded with the fact that we did not find rust or pipe damage during our system observations.

Moreover, 13 of the 16 villagers we surveyed (81%) did not express any additional concerns with the well water. The remaining 3 respondents (19%) presented problems including occasional salty water and discoloration when the water supply returned after a long scarcity period. Figure 16 depicts these concerns. The chart confirms the PDA's information that water scarcity is the primary concern in Baan Tha Lane.

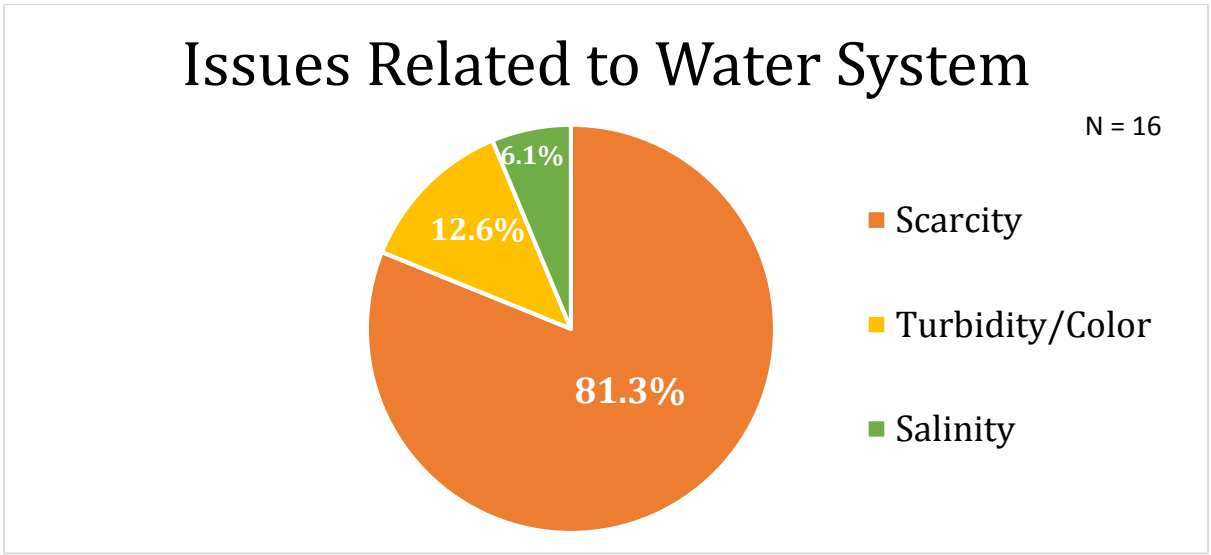

Figure 16: Issues related to water system in Baan Tha Lane

4.2.3 Analysis of Interview with Assistant Leader of Baan Tha Lane

During his interview, Khun Suchart explained that the villagers of Baan Tha Lane had not received water in five days and that these shortages occurred all year long. The community previously called the local government to solve this problem and improve the system. The government had a plan to dig a third well to increase the amount of water to the system. However, the government workers had not made any concrete progress with this plan. We also learned that the Krabi Branch of the PDA had a similar outline for digging a new well. Building upon these ideas, our team formed a third outline for this well that we discuss in the Recommendations and Conclusions chapter. Khun Suchart also informed us that this new well should have a depth of around 100 m, but we could not find adequate information to verify this statement.

We learned from Khun Suchart's responses that our recommendations should not have the villagers rely upon an outside source for maintenance. If the PDA trains a few community members to maintain the distribution system, the residents would not have to continue relying solely on the government to solve their problems with the system.

Multiple parties seemed to think that digging a new well would best solve the water scarcity, but our team still had questions about other solutions to this problem. Particularly, we questioned why the existing two wells could not draw more water by increasing their flow rates with stronger pumps. To answer this question, our team contacted an operator from the Analysis and Planning Department of the local government in Krabi, Khun Sarayut Thongkumchoom. He explained that from past assessments, the government concluded that replacing the existing pumps would not solve the scarcity of water. Therefore, constructing a new well would be the best solution to alleviate the problem.

4.3 Water Quality Testing

Our third objective was to identify and analyze the composition of the water samples from the two villages. The following is a list of the properties we tested at each of the water sources: 1. pH, 2. Iron (Fe), 3. Manganese (Mn), 4. Copper (CU), 5. Zinc (Zn), 6. Fluorine (F), 7. Chloride (Cl), 8. Nitrate (NO_3), 9. Sulfate (SO_4), 10. Total Hardness, 11. Total Dissolved Solids, 12. Conductivity, 13. Turbidity, and 14. Color.

The tests conducted by T-Tech on November 15, 2014 (see Table 5) showed that only well A4 had excessive levels of hardness and iron and B1 had low pH. The other three wells had an acceptable water quality for all properties tested according to the Department of Groundwater Resources' standards in Appendix A. We highlight in yellow all parameters that did not meet the standards.

Table 5: T-Tech Water Quality Results

Test items	Well A1	Well A2	Well A3	Well A4	Well B1	Appropriate Values
pH	7.2	7.2	7.5	7.0	6.0	7.0- 8.5
Total Iron	0.05 mg/L	0.05 mg/L	0.05 mg/L	3.5 mg/L	0.05 mg/L	≤0.5 mg/L
Chloride Ion	40 mg/L	60 mg/L	40 mg/L	40 mg/L	40 mg/L	≤250 mg/L
Total Hardness	100 mg/L	200 mg/L	50 mg/L	250 mg/L	100 mg/L	≤300 mg/L
Total Solid	150 mg/L	220 mg/L	35 mg/L	345 mg/L	75 mg/L	≤600 mg/L

4.3.1 Baan Tha Thong Lang Water Quality Test Results

Table 6 represents the test results for the samples collected from the four wells in Baan Tha Thong Lang during our assessment trip. Appendices I through L contain the official report from the Chulalongkorn Food Research and Testing Laboratory.

Table 6: Baan Tha Thong Lang wells A1-A4 test results from January 29, 2015

Test items	Well A1	Well A2	Well A3	Well A4	Appropriate values
pH	5.05	6.1	5.72	7.2	7.0 -8.5
Iron (Fe)	Not detected	0.05 mg/L	Not detected	0.195 mg/L	≤0.5 mg/L
Manganese (Mn)	Not detected	0.069 mg/L	0.086 mg/L	0.059 mg/L	≤0.3 mg/L
Copper (Cu)	Not detected	Not detected	0.007 mg/L	Not detected	≤1.0 mg/L
Zinc (Zn)	0.035 mg/L	0.028 mg/L	0.017 mg/L	0.021 mg/L	≤5.0 mg/L
Fluoride (F)	Not detected	Not detected	Not detected	0.27 mg/L	≤0.7 mg/L
Chloride (Cl)	4.66 mg/L	6.95 mg/L	5.34 mg/L	5.44 mg/L	≤250 mg/L
Nitrate (NO_3)	< 0.5 mg/L	< 0.5 mg/L	2.45 mg/L	Not detected	≤45 mg/L
Sulfate (SO_4)	7.18 mg/L	8.65 mg/L	7.76 mg/L	55.60 mg/L	≤200 mg/L
Total Hardness	235.26 mg/L	108.08 mg/L	10.81 mg/L	374.01 mg/L	≤300 mg/L
Total Dissolved Solids	267.50 mg/L	173.00 mg/L	42.50 mg/L	405.00 mg/L	≤600 mg/L
Conductivity	448.50 µS/cm	230.00 µS/cm	57.70 µS/cm	708.00 µS/cm	N/A
Turbidity	0.22 NTU	0.58 NTU	0.12 NTU	0.94 NTU	5 NTU
Color	0.56 Pt-Co Unit	0.37 Pt-Co Unit	Not detected	1.11 Pt-Co Unit	5 Pt-Co Unit

According to the Department of Groundwater Resources table in Appendix A, we concluded that only well A4 has excessive hardness levels with a total hardness

measured at 374.01 mg/L. The table shows that the acceptable level for total hardness is less than or equal to 300 mg/L. The other three wells' hardness levels lay in the "Appropriate Value" column. The only other parameter the standards did not deem appropriate were the pH levels in A1, A2, and A3. However, after speaking with an engineer at the Department of Groundwater Resources, we learned that pH levels vary seasonally and our values were not low enough to be a hazard for human health. Therefore, we did not focus on pH in our recommendations.

The major difference between our testing and T-Tech's results is the iron content in well A4. T-Tech's tests, taken before the water treatment, showed high levels of iron. Our tests, taken after the water exits the iron treatment, show the iron levels at 0.195 mg/L which is below the 1.0 mg/L standard found in Appendix A. These results show that the current iron treatment system for well A4 is working adequately and lowering the iron concentration to an acceptable level. This information still leaves the matter of the red precipitates that the villagers reported, unsolved. Therefore, the focus of this well is the water's elevated hardness level and the red precipitate that still remains.

4.3.2 Baan Tha Lane Water Quality Test Results

Table 7 represents the test results for well B1 in Baan Tha Lane. Appendix M contains the full report from the Chulalongkorn Food Research and Testing Laboratory.

Table 7: Baan Tha Lane well B1 test results

Test items	Results	Appropriate values
pH	6.0	7.0 -8.5
Iron (Fe)	Not detected	≤0.5 mg/L
Manganese (Mn)	0.043 mg/L	≤0.3 mg/L
Copper (Cu)	Not detected	≤1.0 mg/L
Zinc (Zn)	0.03 mg/L	≤5.0 mg/L
Fluoride (F)	0.13 mg/L	≤0.7 mg/L
Chloride (Cl)	4.30 mg/L	≤250 mg/L
Nitrate (NO_3)	1.34 mg/L	≤45 mg/L
Sulfate (SO_4)	9.75 mg/L	≤200 mg/L
Total Hardness	67.86 mg/L	≤300 mg/L
Total Dissolved Solids	85.50 mg/L	≤600 mg/L
Conductivity	152.40 µS/cm	N/A
Turbidity	0.16 NTU	5 NTU
Color	Not detected	5 Pt-Co Unit

These tests show that all values except those for pH lay below the maximum acceptable levels according to the table in Appendix A. However, as with Baan Tha Thong Lang, we decided to not focus on the low pH levels. We concluded then that T-Tech's tests showed similar results as the Chulalongkorn Laboratory's tests.

4.3.3 Comparison of Treatment Methods for Hard Water

As the water quality test results for well A4 in Baan Tha Thong Lang showed high levels of hardness in the water, we compared two treatment methods from our

Background chapter; chemical precipitation and ion exchange. We based our comparison on Table 8 below, from the Department of Groundwater Resources, to decide the best method.

Table 8: Comparison of treatment methods

No.	Evaluating topic	Treatment methods	
		Chemical precipitation	Ion exchange
1	**Quality of water**	Good	Good
2	**Costs**		
	- Installation	171,000	150,000
	- Operation	Low	Slightly higher
	- Maintenance	Low	High
3	**Compatibility and convenience**		
	- Difficulty in construction and installation	Medium	Medium
	- Difficulty in operation	Medium	Difficult
	- Difficulty in maintenance	Medium	Difficult
	- Resources can be readily found in area	Medium	Medium

As seen in Table 8, chemical precipitation has a higher installation price than ion exchange because it involves the construction of concrete tanks used to store water for the addition of chemicals. The ion exchange treatment is less expensive to install because the whole system is in a single tank; however, its maintenance is complicated and would require an expert. The overall operational cost for ion exchange is slightly higher since the materials and maintenance are more expensive than those of chemical precipitation. Part of these costs and operation include specialized chemicals and brine recycling or disposal. From this analysis, we believe that chemical precipitation is the most appropriate method for treating the water hardness in well A4.

4.4 Summary

By observing the water systems, our team gathered knowledge of the wells' layouts and noticed a lack of damage to their infrastructure. We recorded the GPS locations of all the wells and observed the iron treatment in well A4.

From the surveys in Baan Tha Thong Lang, we learned that the large majority of the people we spoke to did not believe their well water was safe to drink. Regardless, every single one of them used the water for domestic and sanitation purposes without major concerns, and they were satisfied with the quantity they received. Despite their range of responses for obtaining and treating water, nearly all of those surveyed desired drinking water from the wells. The survey data confirms that the major issue in the village is water quality.

In Baan Tha Lane we learned from our surveys that most of the villagers had water scarcity issues year-round. Nearly all of the people we surveyed had to buy all of their drinking water. However, every single person we questioned would be willing to pay for an improved system if it meant they could receive water for the entire year. There were no major concerns with health problems or infrastructural damage. The surveys made it clear that water quantity was their main problem.

Moreover, from our surveys we found that both Baan Tha Thong Lang and Baan Tha Lane villagers would like to have their water reach drinking standards. However, as we discovered this desire during our field work in the villages, we were only prepared to test for non-drinking standards.

Finally, our water quality tests showed that in Baan Tha Thong Lang, the only points of concern were the high level of total hardness and the red precipitates found in well A4. The iron removal system at A4 treats the high levels of iron that T-Tech's test

results indicated, however, the residents were still concerned about the red iron precipitates visible in the water at times. In Baan Tha Lane, our results showed no presence of water properties exceeding the acceptable parameters for non-drinking standards that we needed to address.

5. Recommendations and Conclusions

This chapter presents our final recommendations to improve the water systems of Baan Tha Thong Lang and Baan Tha Lane. We divide these recommendations into three different sections. The first section focuses on Baan Tha Thong Lang, where we explain the suggested water treatment methods for non-drinking standards with installation and operating costs. In the second section, we estimate ranges of costs for the construction of new infrastructure for the current water system in Baan Tha Lane. We also recommend treatment methods that the PDA may need to implement as a result of this construction. The third section covers recommendations for further research for the PDA. This chapter concludes with a final summary of our project.

5.1 Treat the A4 Well Water in Baan Tha Thong Lang

The most important concerns in Baan Tha Thong Lang are the hard water and red iron precipitates found in well A4. The current filtration does not completely remove the red iron particles or address the high concentration of hardness in the water.

To treat the high levels of hardness, our team recommends installing a chemical precipitation treatment at well A4. The chemical precipitation system must operate along with the iron treatment currently in place. Specifically, the PDA needs to build a set of concrete tanks into the system before the water tower and iron treatment. Figure 17 below depicts this setup with the proposed treatment system.

To decrease the amount of red iron precipitates, we recommend that the community perform more frequent cleaning to the existing iron removal system. The Baan Tha Thong Lang community members currently clean the iron treatment approximately once every two weeks. Therefore, we suggest that the community

members in charge of maintenance begin cleaning the system weekly with backwashing. Backwashing requires pushing water through filters to remove trapped particles such as iron precipitates. This procedure is vital for keeping filters clean to prolong their effectiveness. It also requires no additional tools, and the villagers can perform this process without advanced training. Our team believes this method will decrease the precipitates in the water from well A4 and make it more pleasant for the residents.

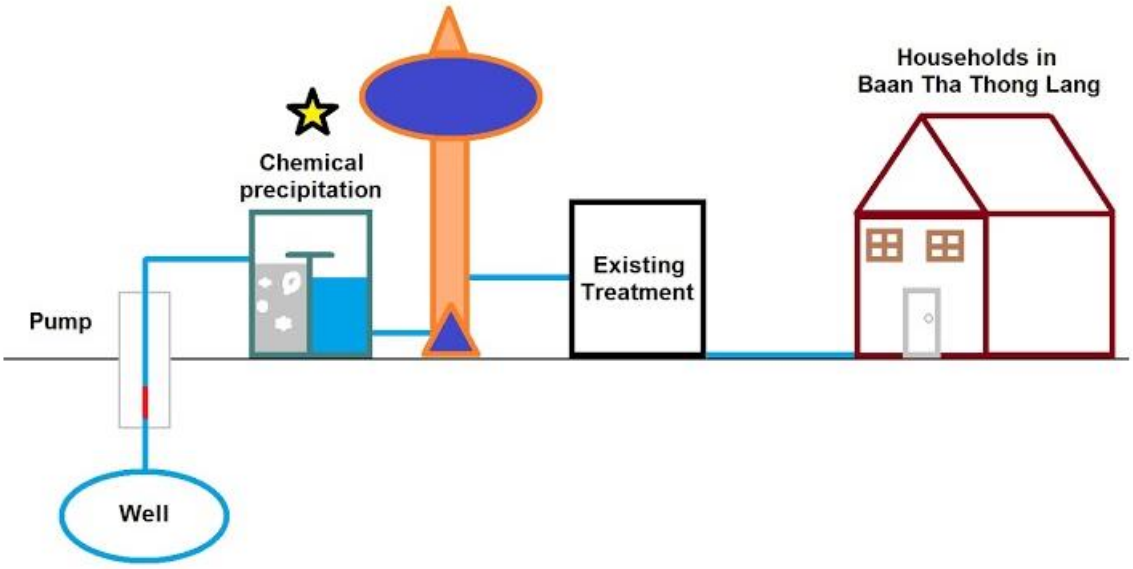

Figure 17: Diagram of proposed Baan Tha Thong Lang well configuration with chemical precipitation treatment system

5.2 Dig a New Well in Baan Tha Lane

Our team concluded that the best option to alleviate water scarcity in this community is to construct a third well in the proximity of the two existing ones. The reason for constructing the well in this location is because the groundwater directly

around Baan Tha Lane is salty and it would be difficult to treat to non-drinking standards. The risk with this solution is that we are unable to determine the exact depth to dig this new well to reach the confined aquifer, which dramatically affects the costs of construction.

For developing a budget range, our team referenced a document published by the Klong Phon sub district municipal government in Krabi. This document contained a detailed table of their budget for digging a well in the province (Konginpaan, 2014). Appendix Q contains all the budget information from this document. We used this table as our reference for obtaining price ranges because of its recent publication date and geographical relation to Baan Tha Lane.

Our team decided to propose three different water system configurations that involve constructing the third well. Each of these three options varies in infrastructure and cost, but they all are feasible solutions. Notice that our team could not acquire sufficient information to thoroughly analyze whether any of these configurations will supply enough water to all the residents of Baan Tha Lane. Therefore, the PDA must carefully consider the costs of each proposal and perform additional analysis of each option before selecting the one they think will best aid Baan Tha Lane.

The first option is the Krabi PDA's outline. In this configuration, the new well would connect to the water tower located before the first village, Baan Chong Kao. The water would then flow through its current path to Baan Tha Lane. Figure 18 below depicts this configuration. Notice that we will discuss the iron treatment in the figure later in the chapter.

The advantage of this proposed configuration is that the PDA would save money by not having to construct a new water path. The weakness of this option is that the water still needs to travel through two other villages before reaching Baan Tha Lane.

Because we do not know the exact depth for the proposed third well, we predict it would be anywhere from 50-130 m deep. Therefore, using the Klong Phon document as a guide, we calculated that this first option would cost between **188,000 to 392,000 Baht.** This considers costs for materials, labor, and evaluation/maintenance of the well.

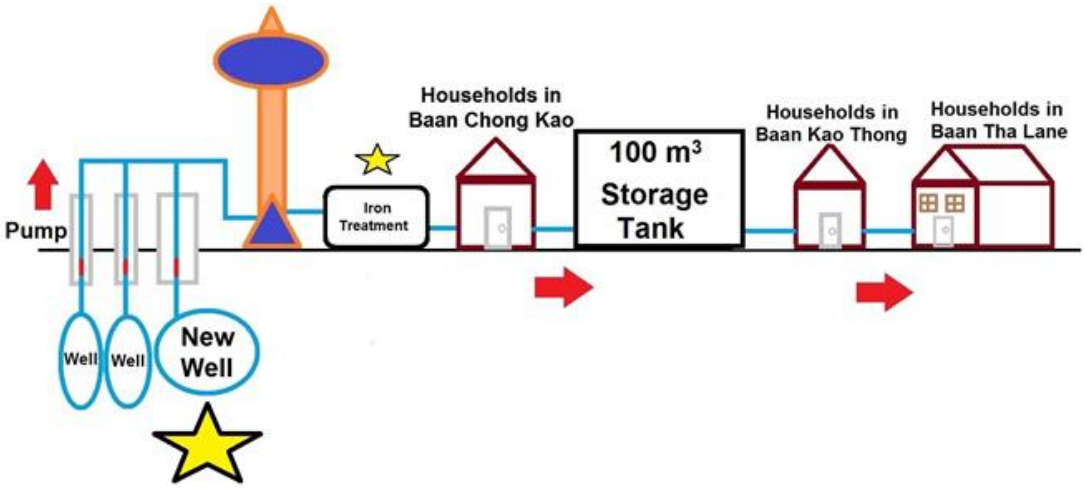

Figure 18: Diagram of first system configuration for Baan Tha Lane with iron treatment system

The second configuration is the local government's outline and would consist of connecting the new well directly to the 100 m^3 storage tank and then connect new piping to Baan Tha Lane. This option utilizes both the current infrastructure and new piping. Figure 19 shows the configuration.

The advantages with this option are that the water from the new well bypasses Baan Chong Kao, and uses the same storage tank that currently exists. The main disadvantages are that in this option, Baan Tha Lane still shares water with Baan Kao Thong and requires new pipe installation. Taking into consideration extra piping for a distance of 1.2 km from the location of the wells to Baan Tha Lane, the approximated budget for well digging, pipes, extra materials, labor, and evaluation/maintenance is between **410,000 to 614,000 Baht.**

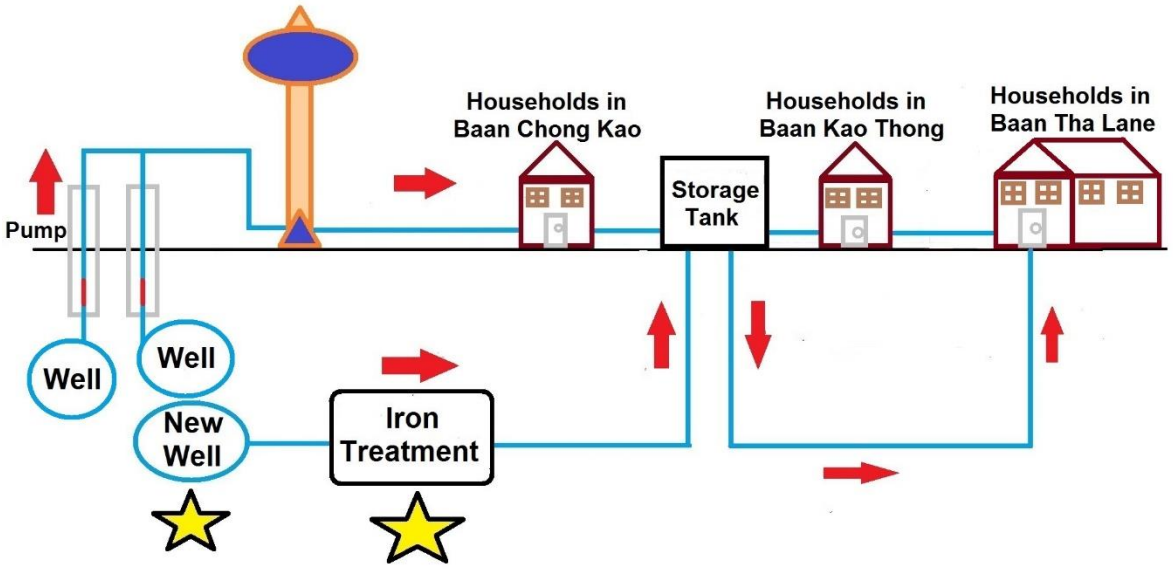

Figure 19: Diagram of second system configuration for Baan Tha Lane with iron treatment system

Lastly, our team designed the outline of the third option, in which the new well would directly connect to Baan Tha Lane by first keeping the water in a new storage tank located before the village's entrance. Figure 20 depicts this configuration.

The benefits of option 3 are that villagers in Baan Tha Lane would be the only ones receiving the water from the new well, in addition to drawing water from the two existing wells. However, this configuration is significantly more expensive than the first two, as it requires the construction of a new storage tank with a pump. Considering the costs for well digging, new piping for a distance of 1.2 km, construction of a new storage tank, a new pump for the tank, extra costs, labor, and evaluation/maintenance, the estimated budget is between **1,026,000 to 1,229,000 Baht.** Appendix Q contains detailed tables explaining the costs of the three proposed configurations.

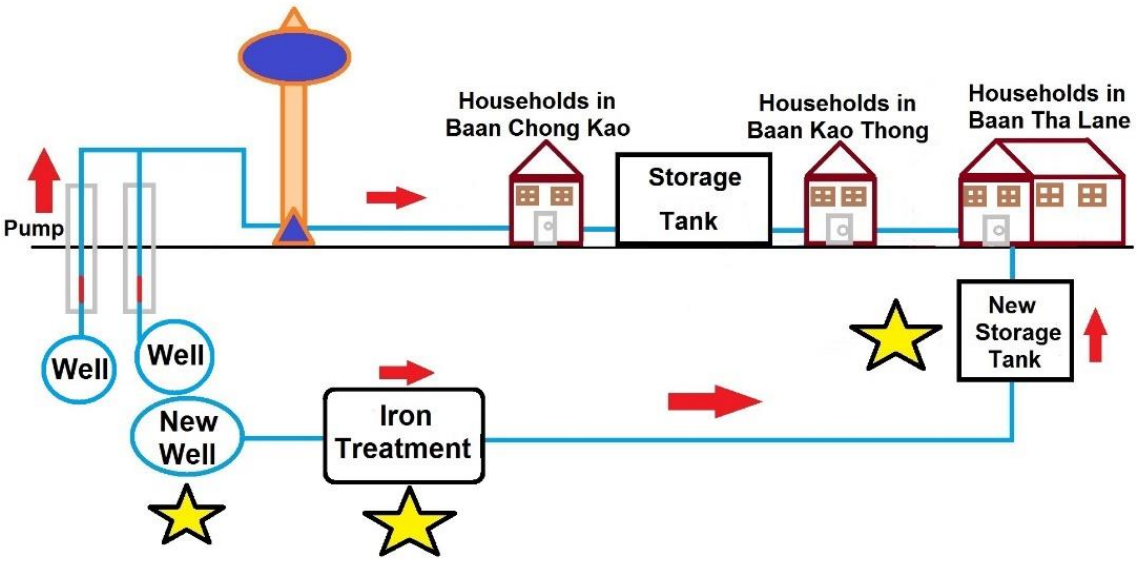

Figure 20: Diagram of third system configuration for Baan Tha Lane with iron treatment system

Furthermore, water quality may also present a potential problem for Baan Tha Lane if they dig a third well. The prior water quality tests conducted by T-Tech and our team's testing results indicate that the water supplied to the village is of acceptable quality for non-drinking purposes. However, it is likely that the third well would draw water from a deeper aquifer. If this is the case, the water from this aquifer runs the risk of containing a high concentration of iron, as is true for the deep well A4, in Baan Tha Thong Lang.

We suggest the PDA test this deeper water to confirm that it meets groundwater standards for iron and other heavy metals. The results of these tests would determine whether or not the system must possess an iron removal method. Our recommendation for reducing iron contents, if needed, is the manganese greensand filtration system. The Department of Groundwater Resources recommends manganese greensand filtration, since it is less complicated and cheaper to construct and operate than other methods. This is similar to the type of treatment used by well A4 in Baan Tha Thong Lang. Figures

18 through 20 above depict the location of the manganese greensand filtration system in the three proposed configurations.

5.3 Recommendations for Further Research for Drinking Standards

From our surveys we found that both Baan Tha Thong Lang and Baan Tha Lane villagers would like to have their water reach drinking standards. However, as we discovered this desire during our field work in the villages, we could not test the water for drinking purposes and receive the results before the project ended. Therefore, our team recommends that the PDA conduct additional water testing for the full range of drinking standards, found in Appendix A, to determine if the water from each well in the villages is safe to drink.

If drinking standard tests reveal that the water is not safe to consume, we recommend the PDA incorporate FCU-8 Softener Water Filtration Systems into the existing water networks. As mentioned in the Background Chapter, this filtration system has the ability to treat all the water properties regulated by the Department of Groundwater Resources for drinking water and is successfully used around the world. The FCU-8 has no residual disinfectant however, so individuals should only collect water directly at the machine.

In Baan Tha Thong Lang, we recommend that the PDA install an FCU-8 unit for each of the four wells in the village. Despite the initial high expenses, there are many advantages to installing the FCU-8 system for all four wells. This plan would ensure adequate volumes of drinking water for all 330 households that use the wells. Additionally, installing an FCU-8 machine for every well would eliminate the need for residents to buy drinking water commercially.

Given the smaller population size of Baan Tha Lane, we believe that a single FCU-8 unit would be sufficient to supply the entire village. The PDA should install the system at a central location in the village to allow the most residents to easily access it.

Table 9 presents detailed information regarding estimated cost ranges and advantages and disadvantages of all the treatment systems proposed above.

Table 9: Summary table of recommendations for water system improvements

	Baan Tha Thong Lang	**Baan Tha Lane**				**Baan Tha Thong Lang and Baan Tha Lane**
Name	**Chemical Precipitation**	**Option 1**	**Option 2**	**Option 3**	**Manganese Greensand Filtration**	**FCU-8 Treatment System**
Estimated cost range (Baht)	150,000 - 190,000	188,000 - 392,000*	410,000 - 614,000*	1,026,000 - 1,229,000*	90,000 per 10 m^3 tank.	58,000
Pros	Treats water hardness Keeps current infrastructure	Least expensive option Keeps current structure	Bypasses the first community Keeps current storage tank	Ensures Baan Tha Lane receives own supply of water Addresses community's recommendations	Presents no concentration of chlorine, no sulphur dioxide, no increase of total dissolved solids, no backwash	Relatively inexpensive Proven reliability Treats to drinking standards
Cons	Relatively inexpensive High maintenance	Still must travel through two villages to reach Baan Tha Lane	Requires new piping structure Water is shared with second community	Very expensive	Must be consistently replenished with a chlorine or permanganate solution.	Requires single distribution site

*This price does not include iron treatment system.

5.4 Conclusions

In conclusion, our project focused on alleviating the water quality in Baan Tha Thong Lang and water scarcity in Baan Tha Lane. Through observations, surveys, interviews, water quality testing, budgeting research, and comparisons of treatment methods, we were able to create a set of recommendations for the PDA to improve the water systems.

In Baan Tha Thong Lang, we propose installing a chemical precipitation system to treat water hardness at well A4, Klong Kruad. We also recommend a cleaning procedure for the existing iron treatment to eliminate the red iron precipitates currently found in the water.

In Baan Tha Lane, we propose to dig a new well near the two existing wells and for the PDA to choose from the three suggested water system configurations, taking into account available funds. In addition, if the water of the new well is high in iron content, we recommend installing a manganese greensand filtration system.

We also recommend further research on testing the well water for drinking purposes, as our surveys showed villagers would like to have their water meet these standards. If needed, we propose the FCU-8 system as a possible treatment for bringing the water to drinkable quality. Installing this system at every well in Baan Tha Thong Lang and Baan Tha Lane will provide drinking water to all village residents.

Finally, by following the solutions discussed in this investigation, the PDA will be able to provide high quality water to over 500 residents in Baan Tha Thong Lang and allow more than 100 residents in Baan Tha Lane to have a constant and reliable source of water. Additionally, the implementation of these solutions will result in a reduction of the villagers' cost of living, as they will no longer need to buy bottled water for drinking and cooking purposes. Finally, if this project is successful, these villages may serve as

examples for addressing similar water problems present in nearby villages in southern Thailand.

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Appendices

Appendix A: Acceptable Standards of Water Testing (Department of Groundwater Resources)

Physical properties

List	Appropriate value	Maximum value
Color	5 (platinum-cobalt scale)	15 (platinum-cobalt scale)
Turbidity	5 (NTU)	20 (NTU)
pH	7.0-8.5	6.5-9.2

Chemical properties

List	Appropriate value (mg/L)	Maximum value (mg/L)
Iron (Fe)	≤0.5	1
Manganese (Mn)	≤0.3	0.5
Copper (Cu)	≤1.0	1.5
Zinc (Zn)	≤5.0	15
Sulfate (SO_4)	≤200	250
Chloride (Cl)	≤250	600
Fluoride (F)	≤0.7	1.0
Nitrate (NO_3)	≤45	45
Total hardness as $CaCO_3$	≤300	500
Non-carbonate hardness as $CaCO_3$	≤200	250
Total dissolved solids	≤600	1,200

Toxicity properties

Lists	Appropriated value	Maximum Value
Arsenic (As)	0.00 mg/L	0.05
Cyanide (CN)	0.00 mg/L	0.1
Lead (Pb)	0.00 mg/L	0.05
Mercury (Hg)	0.00 mg/L	0.001
Cadmium (Cd)	0.00 mg/L	0.01
Selenium (Se)	0.00 mg/L	0.01

Biological/bacteria properties

List	Appropriate value
Standard plate count	≤500 colonies per cm^3
Most probable number of coliform organism (MPN)	<2.2 cm^3
E.coli	0

Appendix B1: Interview Questions for Village Leader of Baan Tha Lane

Hello, we are a joint group of students from Chulalongkorn University in Bangkok and Worcester Polytechnic Institute in the United States. My name is _____, and these are my partners _____. We would like to ask if you have the time to partake in a brief interview about your water system here in **Baan Tha Lane**. My team is working on a research project about water systems sponsored by the PDA so we are analyzing the water distribution systems much like the one here in **Baan Tha Lane**. The purpose of this interview is to better understand the issues that the people of villages in the area are facing related to their water supply and how we can address them.

The interview is completely voluntary. Would you be willing to participate in this interview to help us with our project? Do we have your permission to use your name in our final report and to record this interview?

1. As the leader of this community can you tell us more about your responsibilities?
2. Approximately how many people and households are in this village?
3. What types of work do the people of this village perform?
4. When is a good time/day and where is a good place to interview a large number of villagers? We are looking to conduct at least ten full interviews.
5. Are there any cultural sensitivities we should be aware of when we are in the village and/or speaking to the villagers?
6. What do you think about the current water system?
7. Do you currently use the water system? If so please tell us your own views on it.
8. Does the village use the PDA well water for:
9. Drinking □ **Yes** □ **No**
    a. Do you think that the well water safe for this use?

    YES:

    ii. Do people treat the water before drinking it, such as boiling it? How so?

    NO:

    iii. What source of water do they use instead?

    iv. How much do they spend on this other source of drinking water?

    b. Household use (cooking, washing clothes or dishes) □ **Yes** □ **No**

    i. Do you think that the well water safe for this use?

    YES:

    ii. People treat the water before using it? How so?

    NO:

    iii. What source of water do they use instead?

c. Sanitation □ **Yes** □ **No**

i. Do you think that the well water safe for this use?

YES:

ii. Do people treat the water before using it? How so?

NO:

iii. What source of water do they use instead?

d. Agriculture / livestock □ **Yes** □ **No**

i. Do you think that the well water safe for this use?

YES:

ii. Have people experienced any problems related to the water, such as a decline in crop / livestock health?

NO:

iii. What source of water do they use instead?

10. Do you feel that the village has access to enough water?

a. If no, is the lack of water constant, or is it seasonally based?

11. Have people experienced any sickness that you feel is related to the well water here? □ **Yes** □ **No (if no, move to next question)**

a. What type of sickness have there been?

12. Have people experienced any damage to pipes or pumps, such as corrosion, mineral build up, or leaks that you feel is a result of the water quality? □ **Yes** □ **No (if no, move to next question)**

a. What damages have there been?

13. Have there been any other difficulties related to water supplied by the well system?

□**Yes** □ **No (if no, move to next question)**

a. What difficulties have there been?

14. How was water distributed before the construction of the well here?

a. Did this system work better than the newer system?

15. Is the current water system regularly maintained?

a. If so, by whom?

b. How often?

c. What is the procedure for inspection and maintenance?

d. If you do not know, would you be able to point us to someone who does?

16. Do you believe that people would be willing treat the water themselves or have a large-scale treatment system?

Thank you for your time, your responses will help make a difference in our research.

Appendix B2: Interview Questions for Village Leader of Baan Tha Lane (Thai)

แบบสอบถามสำหรับผู้ใหญ่บ้าน บ้านท่าเลน

สวัสดีครับ/ค่ะ พวกเราเป็นกลุ่มนักศึกษาจากจุฬาลงกรณ์มหาวิทยาลัยที่กรุงเทพและมหาวิทยาลัยวอร์เชสเตอร์ โพลีเทคนิกจากสหรัฐอเมริกา ผม/หนูชื่อ_____ ส่วนนี่คือเพื่อนร่วมกลุ่มของผม/หนูชื่อ_____ พวกเรากำลังศึกษาเกี่ยวกับระบบน้ำ โดยมี PDA เป็นผู้อุปถัมภ์โครงการนี้ พวกเราอยากจะขอรบกวนเวลาสำหรับการสัมภาษณ์เล็กน้อยเกี่ยวกับระบบน้ำของบ้านท่าเลนและบ้านท่าทองหลาง ดังนั้นเราต้องวิเคราะห์ระบบการกระจายน้ำที่หมู่บ้านแห่งนี้ จุดประสงค์ของการมาสัมภาษณ์ครั้งนี้คือทางพวกผมและทางผู้อุปถัมภ์ต้องการที่จะรู้และเข้าใจเกี่ยวกับปัญหาที่ชาวบ้านกำลังเผชิญเกี่ยวกับน้ำประปาให้ดียิ่งขึ้นและหาวิธีจัดการกับปัญหาเหล่านี้เพื่อเสนอต่อ PDA

ในการสัมภาษณ์ครั้งนี้ไม่ได้เป็นการบังคับให้ทำแต่อย่างใดแต่ให้ทำตามความสมัครใจ คุณจะพอสละเวลามาทำแบบสอบถามนี้ของเราได้หรือไม่? เราสามารถที่จะอ้างอิงชื่อของคุณในรายงานรูปเล่มและบันทึกการสัมภาษณ์ครั้งนี้ไว้ได้หรือไม่?

1. ในฐานะที่คุณเป็นผู้ใหญ่บ้านของชุมชนนี้ คุณสามารถบอกข้อมูลเกี่ยวกับหน้าที่การงานของคุณเพิ่มเติมให้กับทางเราหน่อยได้หรือไม่?
2. ที่ชุมชนแห่งนี้มีชาวบ้านอาศัยอยู่กี่คนและครอบครัวกี่ครอบครัว? (โดยประมาณ)
3. ชาวบ้านในชุมชนแห่งนี้ทำอาชีพอะไรเป็นส่วนใหญ่?
4. คุณคิดว่าเมื่อไหร่และที่ไหนที่เหมาะสมต่อการสอบถามข้อมูลชาวบ้านจำนวนมาก? เพราะทางเราต้องการชาวบ้านอย่างน้อย 10 คนในการทำแบบสอบถาม
5. คุณพอจะทราบหรือไม่ว่ามีประเพณีหรือวัฒนธรรมอะไรที่เราควรระวังเป็นพิเศษหรือเปล่าในขณะที่เราสัมภาษณ์ชาวบ้านอยู่? (เช่น การแต่งตัว, การทักทาย, ฯลฯ)
6. ทางเราอยากสอบถามเพิ่มว่าคุณคิดยังไงกับระบบน้ำที่ใช้อยู่ในปัจจุบัน?
7. คุณช่วยอธิบายการวางระบบน้ำจากชั้นหินอุ้มน้ำไปไปตามบ้านเรือนในหมู่บ้านได้หรือไม่อย่างไร?
8. คนในหมู่บ้านนี้ใช้น้ำจากบ่อบาดาลของ PDA เพื่ออะไร
   a. สำหรับดื่มกิน □ ใช่ □ ไม่ใช่
      i. คุณคิดว่าน้ำจากแหล่งเก็บน้ำนี้ปลอดภัยหรือไม่?

         ใช่:
      ii. ชาวบ้านในชุมชนแห่งนี้มีวิธีการฆ่าเชื้อน้ำก่อนดื่มหรือไม่? อย่างไร?

         ไม่ใช่:
      iii. ชาวบ้านใช้น้ำจากที่ไหน?
      iv. พวกเค้าต้องใช้จ่ายค่าน้ำจากแหล่งน้ำนี้เท่าไหร่?
   b. ชาวบ้านใช้น้ำนี้สำหรับการดำรงชีวิตประจำวัน(เช่น ล้างจาน ซักเสื้อผ้า เป็นต้น)

      □ ใช่ □ ไม่ใช่
      i. คุณคิดว่าน้ำนี้ปลอดภัยพอสำหรับการดำรงชีวิตหรือไม่?

         ใช่:
      ii. ชาวบ้านฆ่าเชื้อโรคก่อนหรือไม่? ด้วยวิธีใด?

         ไม่ใช่:

iii. ชาวบ้านในชุมชนนี้ใช้น้ำจากแหล่งน้ำไหน?

c. ชาวบ้านใช้น้ำสำหรับสุขาอนามัย □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?
ใช่:

ii. ชาวบ้านในชุมชนแห่งนี้มีการฆ่าเชื้อก่อนใช้หรือไม่? ด้วยวิธีใด?
ไม่ใช่:

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

d. เกษตรกรรม/ปศุสัตว์ □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?
ใช่:

ii. เคยมีชาวบ้านคนไหนบ้างที่เคยมีปัญหาทางเกษตรกรรมและปศุสัตว์เพราะน้ำจากแหล่งน้ำแห่งนี้ เช่น พืชคุณภาพไม่ดี/สุขภาพของสัตว์ไม่แข็งแรง?
ไม่ใช่:

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

9. ชุมชนแห่งนี้กำลังประสบปัญหาน้ำขาดแคลนอยู่หรือไม่?

a. ถ้าไม่ คุณคิดว่าอะไรเป็นปัจจัยทำให้การกระจายน้ำถูกจำกัด?

b. ถ้าใช่ สาเหตุที่น้ำขาดแคลนเป็นเพราะฤดูแล้งใช่หรือไม่?

10. มีชาวบ้านคนไหนเคยประสบปัญหาในเรื่องของโรคภัยไข้เจ็บเพราะน้ำจากแหล่งน้ำนี้บ้างหรือไม่? □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ข้ามไปถามข้อถัดไป**)**

a. โรคภัยไข้เจ็บประเภทใดที่ชาวบ้านเป็น?

11. เคยมีเหตุการณ์ประสบเหตุปั๊มหรือท่อส่งน้ำเสียหายบ้างไหม? ยกตัวอย่างเช่นการกร่อน หินปูน หรือจุดแตก ที่อาจเกิดขึ้นได้จากปัญหาของคุณภาพน้ำ □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

12. มีปัญหาอะไรที่เกี่ยวข้องกับแหล่งน้ำจากระบบน้ำนี้หรือไม่? □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

a. ปัญหาที่เกี่ยวข้องมีอะไรบ้าง?

13. ควรมีการพัฒนาระบบน้ำหรือไม่ ? □ ใช่ □ ไม่ใช่

a. อยากเปลี่ยนอย่างไร?

b. ทำไมจึงอยากเปลี่ยน?

14. ก่อนหน้าที่ระบบน้ำนี้ถูกสร้างขึ้น ทางหมู่บ้านได้มีระบบการกระจายน้ำด้วยวิธีใด?

a. การใช้งานของระบบดังกล่าวนั้นดีกว่าระบบปัจจุบันหรือไม่?

15. ระบบน้ำปัจจุบันได้รับการซ่อมแซมดูแลบ้างหรือไม่?

a. ถ้าใช่ โดยใคร?
b. บ่อยแค่ไหน?
c. กระบวนการตรวจสอบและซ่อมแซมเป็นอย่างไร?

d. หากคุณไม่ทราบเรื่องระบบ พอจะรู้จักบุคคลใดที่ทราบเรื่องนี้ไหม?

16. คุณคิดว่าชาวบ้านจะให้ความร่วมมือในการบำบัดน้ำด้วยตนเองหรือระบบบำบัดน้ำด้วยเครื่องมือขนาดใหญ่มากกว่ากัน?

ขอบพระคุณที่สละเวลาครับ/ค่ะ ทางเรายินดีที่ได้รับทราบข้อเท็จจริงและความคิดเห็นของคุณ

Appendix C1: Survey Questions for Community Members of Baan Tha Thong Lang

Interviewer(s): Date: Time: Location: Gender:

Hello, we are a joint group of students from Chulalongkorn University in Bangkok and Worcester Polytechnic Institute in the United States. My name is _____, and these are my partners _____. We would like to ask if you have the time to partake in a brief interview about your water system here in Baan Tha Lane/ Baan Tha Thong Lang. My team is working on a research project about water systems sponsored by the PDA so we are analyzing the water distribution systems much like the one here in Baan Tha Lane/ Baan Tha Thong Lang. The purpose of this interview is to better understand the issues that the people of villages in the area are facing related to their water supply and how we can address them.
This survey is completely voluntary. This information will be kept anonymous and confidential. Would you be willing to participate in this interview to help us with our project?

1. What is your occupation?
2. How old are you? (We may not be able to ask this question depending on cultural norms, so to gauge age if that is the case we have included the next question)
   a. □ Less than 15
   b. □ 15-24
   c. □ 25-34
   d. □ 35-44
   e. □ 45-54
   f. □ 55-64
   g. □ Over 65
3. How long have you lived in Baan Tha Thong Lang?
   . □ Less than 10 years
   a. □ 10-19
   b. □ 20-29
   c. □ 30-39
   d. □ 40-49
   e. □ 50 years or more
4. From what source do you receive your drinking water from?
5. Do you use government water for household use (washing clothes or dishes?)
   . Do you think that the well water is safe for this use?

      YES:

      i. Do you treat the water before using it? How so?

      NO:

      ii. From what source do you receive your water from?
6. Do you use government water for agriculture / livestock use? □ **Yes** □ **No**

a. Do you think that the well water is safe for this use?

YES:

i. Have you experienced any problems related to the water, such as a decline in crop / livestock health?

NO:

ii. From what source do you receive your water from?

7. Do you use government water for agriculture / livestock use? □ **Yes** □ **No**

   a. Do you think that the well water is safe for this use?

   YES:

   i. Have you experienced any problems related to the water, such as a decline in crop / livestock health?

   NO:

   ii. From what source do you receive your water from?

8. What is your overall opinion about the current water system?
9. Have you experienced any personal sickness that you feel is related to the well water here? □ **Yes** □ **No (if no, move to next question)**

   . What kind of sickness have you experienced?

10. Have you experienced any damage to personal effects or appliances, such as corrosion or mineral build up that you feel is a result of the water quality? □ **Yes** □ **No (if no, move to next question)**

    . What damages have you experienced?

11. Are there any other difficulties you have experienced related to water supplied by the well system? □**Yes** □ **No (if no, move to next question)**

    . What difficulties have you experienced?

12. Would you want make any changes to the current water system? □ **Yes** □ **No (if no, move to next question)**

    . What would these changes be?

    a. Why would you like to make these changes?

13. If you lived here before the government constructed the well, did you prefer how water was distributed before or after the construction? □ **Before** □ **After**

    . Did you prefer the water quality before or after the construction? □ **Before** □ **After**

Thank you for your time, your responses will help make a difference in our research.

Appendix C2: Survey Questions for Community Members of Baan Tha Thong Lang (Thai)

แบบสอบถามสำหรับชาวบ้านในชุมชนบ้านท่าทองหลาง

ผู้สอบถาม: วันที่: เวลา: สถานที่:

สวัสดีครับ/ค่ะ พวกเราเป็นกลุ่มนักศึกษาจากจุฬาลงกรณ์มหาวิทยาลัยที่กรุงเทพและมหาวิทยาลัยวอร์เชสเตอร์ โพลีเทคนิกจากสหรัฐอเมริกา ผม/หนูชื่อ_____ ส่วนนี่คือเพื่อนร่วมกลุ่มของผม/หนูชื่อ_____ พวกเรากำลังศึกษาเกี่ยวกับระบบน้ำ โดยมี PDA เป็นผู้อุปถัมภ์โครงการนี้ พวกเราอยากจะขอรบกวนเวลาสำหรับการสัมภาษณ์เล็กน้อยเกี่ยวกับระบบน้ำของบ้านท่าเลนและบ้านท่าทองหลาง ดังนั้นเราต้องวิเคราะห์ระบบการกระจายน้ำที่หมู่บ้านแห่งนี้ จุดประสงค์ของการมาสัมภาษณ์ครั้งนี้คือทางพวกผมและทางสปอนเซอร์ต้องการที่จะรู้และเข้าใจเกี่ยวกับปัญหาที่ชาวบ้านกำลังเผชิญเกี่ยวกับน้ำประปาอยู่ได้ดียิ่งขึ้นและหาวิธีจัดการกับปัญหาเหล่านี้เพื่อเสนอต่อ PDA

ในการสัมภาษณ์ครั้งนี้ไม่ได้เป็นการบังคับให้ทำแต่อย่างใดแต่ให้ทำตามความสมัครใจ คุณจะพอสละเวลามาทำแบบสอบถามนี้ของเราได้หรือไม่? เราสามารถที่จะอ้างอิงชื่อของคุณในรายงานรูปเล่มและบันทึกการสัมภาษณ์ครั้งนี้ไว้ได้หรือไม่?

1. คุณประกอบอาชีพอะไร?
2. คุณอายุเท่าไหร่? (เราอาจจะไม่สามารถถามคำถามนี้ได้เนื่องจากในเรื่องของวัฒนธรรม แต่คำถามต่อไปก็สอดคล้องกับคำตอบอยู่แล้ว)
   a. □ น้อยกว่า 15
   b. □ 15-24
   c. □ 25-34
   d. □ 35-44
   e. □ 45-54
   f. □ 55-64
   g. □ มากกว่า 64
3. คุณอยู่ในหมู่บ้านนี้มานานแค่ไหนแล้ว? (บ้านท่าเลน/ท่าทองหลาง)
   a. □ น้อยกว่า 10 ปี
   b. □ 10-19
   c. □ 20-29
   d. □ 30-39
   e. □ 40-49
   f. □ 50 หรือมากกว่า
4. คุณใช้น้ำจากแหล่งเก็บน้ำเพื่อวัตถุประสงค์ใด? :
   a. สำหรับดื่มกิน □ ใช่ □ ไม่ใช่
      i. คุณคิดว่าน้ำจากแหล่งเก็บน้ำนี้ปลอดภัยหรือไม่?

   ใช่:

      ii. คุณมีวิธีการบำบัดน้ำก่อนดื่มหรือไม่? ด้วยวิธีใด?

   ไม่ใช่:

iii. คุณใช้น้ำจากที่ไหนแทน?

b. คุณใช้น้ำนี้สำหรับการดำรงชีวิตประจำวัน(เช่น ล้างจาน ซักเสื้อผ้า เป็นต้น)

□ ใช่ □ ไม่ใช่

i. คุณคิดว่าน้ำนี้ปลอดภัยพอสำหรับการดำรงชีวิตหรือไม่?

ใช่:

ii. ชาวบ้านบำบัดก่อนหรือไม่? อย่างไร?

ไม่ใช่:

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

c. ชาวบ้านใช้น้ำสำหรับสุขาภิบาล □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?

ใช่:

ii. ชาวบ้านในชุมชนแห่งนี้มีการบำบัดก่อนใช้ใช้หรือไม่? อย่างไร?

ไม่ใช่:

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

d. เกษตรกรรม/ปศุสัตว์ □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?

ใช่:

ii. เคยมีชาวบ้านคนไหนบ้างที่เคยมีปัญหาทางเกษตรกรรมและปศุสัตว์เพราะน้ำจากแหล่งน้ำแห่งนี้ เช่น พืชคุณภาพไม่ดี/สุขภาพของสัตว์ไม่แข็งแรง?

ไม่ใช่:

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

5. ความคิดเห็นโดยรวมเกี่ยวกับระบบน้ำปัจจุบันของคุณคืออะไร?

6. คุณคิดว่าหมู่บ้านแห่งนี้ได้ใช้น้ำได้เพียงพอหรือไม่?

a. ถ้าไม่ คุณคิดว่าอะไรเป็นตัวการทำให้การกระจายน้ำถูกจำกัด?

b. ถ้าใช่ สาเหตุที่น้ำขาดแคลนคือฤดูแล้งใช่หรือไม่?

7. คุณคนไหนเคยประสบปัญหาในเรื่องของโรคภัยไข้เจ็บเพราะน้ำจากแหล่งน้ำที่นี้บ้างหรือไม่?
□ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ข้ามไปถามข้อถัดไป**)**

a. ป่วยเป็นโรคอะไร

8. คุณเคยประสบปัญหาข้าวของเครื่องใช้ส่วนตัวเคยเสียหายบ้างหรือไม่ เช่น การกัดกร่อนหรือการก่อตัวของแร่ธาตุ คุณคิดว่าสิ่งเหล่านี้เป็นผลมาจากคุณภาพของน้ำหรือไม่? □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

a. ความเสียหายที่กล่าวมานั้นคืออะไร?

9. คุณเคยประสบเหตุท่อน้ำพังบ้างไหม? ยกตัวอย่างเช่นการกร่อน หินปูน หรือจุดแตก ที่อาจเกิดขึ้นได้จากปัญหาของคุณภาพน้ำ □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

10. มีปัญหาอะไรที่เกี่ยวข้องกับแหล่งน้ำจากระบบน้ำนี้หรือไม่? □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

    a. ปัญหาที่คุณเคยเจอคืออะไร?

11. คุณคิดว่าระบบน้ำปัจจุบันควรได้รับการเปลี่ยนแปลงหรือไม่? □ ใช่ □ ไม่ใช่ **(**ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป**)**

    a. การเปลี่ยนแปลงควรมีอะไรบ้าง?

    b. อะไรคือเหตุผลของการเปลี่ยนแปลงดังกล่าว?

12. ถ้าคุณเคยอยู่ที่นี่มาก่อนที่ PDA จะสร้างแหล่งเก็บน้ำ คุณชอบน้ำที่ถูกจ่าย ก่อนหน้านี้หรือหลังจากที่สร้าง ? □ ก่อน □ หลัง

    a. คุณชอบคุณภาพน้ำที่ถูกจ่าย ก่อนหน้านี้หรือหลังจากที่สร้าง? □ ก่อน □ หลัง

    *(*อาจมีส่วนช่วยให้เราเข้าใจเรื่องวิธีบำบัดที่สามารถปรับใช้กับระบบน้ำปัจจุบัน หากชาวบ้านต้องการแบบนั้นมากกว่า*)*

ขอบพระคุณที่สละเวลาครับ/ค่ะ ทางเรายินดีที่ได้รับทราบข้อเท็จจริงและความคิดเห็นของคุณ

Appendix D1: Survey Questions for Community Members of Baan Tha Lane

Interviewer(s): Date: Time: Location:

Hello, we are a joint group of students from Chulalongkorn University in Bangkok and Worcester Polytechnic Institute in the United States. My name is _____, and these are my partners _____. We would like to ask if you have the time to partake in a brief interview about your water system here in Baan Tha Lane/ Baan Tha Thong Lang. My team is working on a research project about water systems sponsored by the PDA so we are analyzing the water distribution systems much like the one here in Baan Tha Lane/ Baan Tha Thong Lang. The purpose of this interview is to better understand the issues that the people of villages in the area are facing related to their water supply and how we can address them.
This survey is completely voluntary. This information will be kept anonymous and confidential. Would you be willing to participate in this interview to help us with our project?

1. What is your occupation?
2. How old are you? (We may not be able to ask this question depending on cultural norms, so to gauge age if that is the case we have included the next question)
   a. □ Less than 15
   b. □ 15-24
   c. □ 25-34
   d. □ 35-44
   e. □ 45-54
   f. □ 55-64
   g. □ Over 64
3. How long have you lived in Baan Tha Lane/ Baan Tha Thong Lang?
   . □ Less than 10 years
   a. □ 10-19
   b. □ 20-29
   c. □ 30-39
   d. □ 40-49
   e. □ 50 or More
4. Do you use the well water for:
   . Drinking □ **Yes** □ **No**
      i. Do you think that the well water safe for this use?

   YES:

      ii. Do you treat the water before using it, such as boiling it? How so?

   NO:

      iii. What source of water do you use instead?

   b. Household use (cooking, washing clothes or dishes) □ **Yes** □ **No**
      i. Do you think that the well water safe for this use?

YES:

ii. Do you treat the water before using it? How so?

NO:

iii. What source of water do you use instead?

c. Sanitation □ **Yes** □ **No**

i. Do you think that the well water safe for this use?

YES:

ii. Do you treat the water before using it? How so?

NO:

iii. What source of water do you use instead?

d. Agriculture / livestock □ **Yes** □ **No**

i. Do you think that the well water safe for this use?

YES:

ii. Have you experienced any problems related to the water, such as a decline in crop / livestock health?

NO:

iii. What source of water do you use instead?

5. What is your overall opinion about the current water system?
6. Would you rather pay for a new system constructed in this village or continue buying water?
7. Do you feel that you have access to enough water?
   a. If not, what do you think is limiting your access?
   b. Is your lack of water constant, or is it seasonally based?
8. Have you experienced any personal sickness that you feel is related to the well water here? □ **Yes** □ **No (if no, move to next question)**
   a. What type of sickness have you experienced?
9. Have you experienced any damage to your pipes, such as corrosion, mineral build up, or leaks that you feel is a result of the water quality? □ **Yes** □ **No (if no, move to next question)**
   a. What damages have you experienced?
10. Are there any other difficulties you have experienced related to water supplied by the well system? □ **Yes** □ **No (if no, move to next question)**
    a. What difficulties have you experienced?
11. Would you want to make any improvements to the current water system? □ **Yes** □ **No (if no, move to next question)**
    a. What would these improvements be?

b. Why would you like to make these changes?

12. What is your opinion of the water usage from the hotels in the area?

Thank you for your time, your responses will help make a difference in our research.

Appendix D2: Survey Questions for Community Members of Baan Tha Lane (Thai)

แบบสอบถามสำหรับชาวบ้านในชุมชนบ้านท่าเลน

ผู้สอบถาม: วันที่: เวลา: สถานที่:

สวัสดีครับ/ค่ะ พวกเราเป็นกลุ่มนักศึกษาจากจุฬาลงกรณ์มหาวิทยาลัยที่กรุงเทพและมหาวิทยาลัยวอร์เชสเตอร์ โพลีเทคนิกจากสหรัฐอเมริกา ผม/หนูชื่อ_____ ส่วนนี่คือเพื่อนร่วมกลุ่มของผม/หนูชื่อ_____ พวกเรากำลังศึกษาเกี่ยวกับระบบน้ำ โดยมี PDA เป็นผู้อุปถัมภ์โครงการนี้ พวกเราอยากจะขอรบกวนเวลาสำหรับการสัมภาษณ์เล็กน้อยเกี่ยวกับระบบน้ำของบ้านท่าเลนและบ้านท่าทองหลาง ที่สร้างขึ้นมาโดย PDA ดังนั้นเราต้องวิเคราะห์ระบบการกระจายน้ำที่หมู่บ้านแห่งนี้ จุดประสงค์ของการมาสัมภาษณ์ครั้งนี้คือทางพวกผมและทางสปอนเซอร์ต้องการที่จะรู้และเข้าใจเกี่ยวกับปัญหาที่ชาวบ้านกำลังเผชิญเกี่ยวกับน้ำประปาอยู่ได้ดียิ่งขึ้นและหาวิธีจัดการกับปัญหาเหล่านี้เพื่อเสนอต่อ PDA

ในการสัมภาษณ์ครั้งนี้ไม่ได้เป็นการบังคับให้ทำแต่อย่างใดแต่ให้ทำตามความสมัครใจ คุณจะพอสละเวลามาทำแบบสอบถามนี้ของเราได้หรือไม่? เราสามารถที่จะอ้างอิงชื่อของคุณในรายงานรูปเล่มและบันทึกการสัมภาษณ์ครั้งนี้ไว้ได้หรือไม่?

1. คุณประกอบอาชีพอะไร?
2. คุณอายุเท่าไหร่? (เราอาจจะไม่สามารถถามคำถามนี้ได้เนื่องจากในเรื่องของวัฒนธรรม แต่คำถามต่อไปก็สอดคล้องกับคำตอบอยู่แล้ว)
   a. □ น้อยกว่า 15
   b. □ 15-24
   c. □ 25-34
   d. □ 35-44
   e. □ 45-54
   f. □ 55-64
   g. □ มากกว่า 64

   h. คุณอยู่ในหมู่บ้านนี้มานานแค่ไหนแล้ว ? (บ้านท่าเลน/ท่าทองหลาง)

   a. □ น้อยกว่า 10 ปี
   b. □ 10-19
   c. □ 20-29
   d. □ 30-39
   e. □ 40-49
   f. □ 50 หรือมากกว่า
3. คุณใช้น้ำจากแหล่งเก็บน้ำเพื่อวัตถุประสงค์ใด?

   . สำหรับดื่มกิน □ **ใช่** □ **ไม่ใช่**

   คุณคิดว่าน้ำจากแหล่งเก็บน้ำนี้ปลอดภัยหรือไม่?

   ใช่**:**

   คุณมีวิธีการบำบัดน้ำก่อนดื่มหรือไม่? ด้วยวิธีใด?

   ไม่ใช่**:**

   คุณใช้น้ำจากที่ไหน?

   b. คุณใช้น้ำนี้สำหรับการดำรงชีวิตประจำวัน(เช่น ล้างจาน ซักเสื้อผ้า เป็นต้น) □ ใช่ □ ไม่ใช

   i. คุณคิดว่าน้ำนี้ปลอดภัยพอสำหรับการดำรงชีวิตหรือไม่?

   ใช่**:**

ii. ชาวบ้านบำบัดก่อนหรือไม่? ด้วยวิธีใด?

ไม่ใช่**:**

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

c. ชาวบ้านใช้น้ำสำหรับสุขอนามัย □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?

ใช่**:**

ii. ชาวบ้านในชุมชนแห่งนี้มีการบำบัดก่อนใช้ใช้หรือไม่? วิธีใด?

ไม่ใช่**:**

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

d. เกษตรกรรม/ปศุสัตว์ □ ใช่ □ ไม่ใช่

i. คิดว่าน้ำจากแหล่งน้ำนี้ปลอดภัยพอที่จะใช้หรือไม่?

ใช่**:**

ii. เคยมีชาวบ้านคนไหนบ้างที่เคยมีปัญหาทางเกษตรกรรมและปศุสัตว์เพราะน้ำจากแหล่งน้ำแห่งนี้ เช่น พืชคุณภาพไม่ดี/สุขภาพของสัตว์ไม่แข็งแรง?

ไม่ใช่**:**

iii. น้ำจากแหล่งน้ำไหนที่สามารถใช้ทดแทนแหล่งน้ำนี้ได้?

4. ความคิดเห็นโดยรวมเกี่ยวกับระบบน้ำปัจจุบันของคุณคืออะไร?

5. คุณอยากที่จะจ่ายเงินสำหรับระบบน้ำในหมู่บ้านนี้ใหม่หรือจะยังคงซื้อน้ำใช้เหมือนเดิม?

6. คุณคิดว่าหมู่บ้านแห่งนี้ได้ใช้น้ำได้เพียงพอหรือไม่?

a. ถ้าไม่ คุณคิดว่าอะไรเป็นตัวการทำให้การกระจายน้ำถูกจำกัด?

b. ถ้าใช่ สาเหตุที่น้ำขาดแคลนคือฤดูแล้งใช่หรือไม่?

7. คุณคนไหนเคยประสบปัญหาในเรื่องของโรคภัยไข้เจ็บเพราะน้ำจากแหล่งน้ำนี้บ้างหรือไม่? □ **ใช่** □ **ไม่ใช่ (ถ้าไม่ใช่ ให้ข้ามไปถามข้อถัดไป)**

a. ป่วยเป็นโรคอะไร?

8. คุณเคยประสบเหตุท่อน้ำเสียหายบ้างไหม? ยกตัวอย่างเช่นการกร่อน หินปูน หรือจุดแตก ที่อาจเกิดขึ้นได้จากปัญหาของคุณภาพน้ำ □ **ใช่** □ **ไม่ใช่ (ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป)** เสียหายอย่างไร?

9. มีปัญหาอะไรที่เกี่ยวข้องกับแหล่งน้ำจากระบบน้ำนี้หรือไม่? □ **ใช่** □ **ไม่ใช่ (ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป)**

a. ปัญหาที่คุณเคยเจอคืออะไร?

10. คุณคิดว่าระบบน้ำปัจจุบันควรได้รับการพัฒนาหรือไม่? □ **ใช่** □ **ไม่ใช่ (ถ้าไม่ใช่ ให้ย้ายไปคำถามถัดไป)**

a. การเปลี่ยนแปลงควรมีอะไรบ้าง?

b. อะไรคือเหตุผลของการเปลี่ยนแปลงดังกล่าว?

11. คุณคิดอย่างไรกับการใช้น้ำของโรงแรม?

ขอบพระคุณที่สละเวลาครับ/ค่ะ ทางเรายินดีที่ได้รับทราบข้อเท็จจริงและความเห็นของคุณ

Appendix E1: Interview Questions for Head of PDA in Krabi

Interviewer(s): Date: Time: Location: Gender:

Hello, my name is _____, and these are my partners _____. As you know, we are undertaking a research project that is sponsored by the PDA here in Krabi. The purpose of this interview is to gain more knowledge on the specific problems the villages are currently facing due to their water systems and to better understand the expectations the PDA has for us.

This interview is completely voluntary and we will need your consent to record the interview and take written notes. Would you be willing to participate in this interview to help us with our project?

Do we have your permission to use your name in our final report?

General:

1. Please explain the current situation in Baan Tha Thong Lang and Baan Tha Lane.
2. Can you please guide us as to what your expectations are for us?
3. Do you perceive any hurdles that could hinder the success of this assignment for our team?

Social:

4. What are some examples of issues the villagers from both villages are experiencing in regards to the water systems (health, damaged appliances, etc.)?
5. We are planning on conducting interviews with the villagers, is there anything we should be aware of when speaking one-on-one with people?
6. Is it appropriate for us to interview women?

Economic:

7. Are the villagers currently paying for the services the PDA is providing through the well system? (E.g. water to the home appliances, water from the tanks, etc.) If yes, may we ask how much they are paying?

Technical:

8. Can you explain to us the layout of the systems from the aquifer to the households?
9. Are there currently any maintenance procedures performed on the systems?
    a. If so, who does them?
    b. If so, how often?
    c. If so, what is the procedure?
10. Do you have maintenance records we can have access to?

Additional Questions:

11. Is there any additional information you may able to provide to improve our understanding of this problem?
12. Could you provide us with any contact information of specialists that may help our understanding of this project, such as water quality experts or civil engineers?

13. Are there any places near Krabi City where we could perform tests on any water samples we collect here?

Thank you for your time, your responses will help make a difference in our research.

Appendix E2: Interview Questions for Head of PDA in Krabi (Thai)

แบบสอบถามหัวหน้า PDA สาขากระบี่

ผู้สอบถาม: วันที่: เวลา: สถานที่:

สวัสดีค่ะ/ครับ ดิฉัน/ผม ชื่อ _____ และนี่คือผู้ร่วมงานของดิฉัน/ผม _____ อย่างที่คุณอำนวยได้ทราบแล้วว่าพวกเราะดำเนินการโครงการวิจัยที่ได้รับการอุปถัมภ์โดย PDA ที่กระบี่ วัตถุประสงค์ของการสัมภาษณ์ครั้งนี้คือการได้รับความรู้เพิ่มเติมเกี่ยวกับปัญหาที่เฉพาะเจาะจงของหมู่บ้านที่กำลังเผชิญอยู่สืบเนื่องจากระบบน้ำของพวกเขา และเพื่อให้เข้าใจถึงความต้องการของ PDA ที่มีสำหรับเรามากขึ้น

ในการสัมภาษณ์ครั้งนี้ไม่ได้เป็นการบังคับให้ทำแต่อย่างใดแต่ให้ทำตามความสมัครใจ คุณจะพอสละเวลามาทำแบบสอบถามนี้ของเราได้หรือไม่? เราสามารถที่จะอ้างอิงชื่อของคุณในรายงานรูปเล่มและบันทึกการสัมภาษณ์ครั้งนี้ไว้ได้หรือไม่?

ทั่วไป

1. ช่วยอธิบายสถานการณ์เกี่ยวกับปัญหา ปัจจุบันในบ้านท่าทองหลางและบ้านท่าเลน
2. ความต้องการของคุณที่ต้องการให้เราแก้ปัญหาคืออะไร
3. คุณพอจะทราบว่าอะไรที่อาจเป็นอุปสรรคต่อความสำเร็จของการทำงานของเราครั้งนี้หรือไม่?

สังคม

4. ปัญหาที่ชาวบ้านจากหมู่บ้านทั้งสองกำลังประสบในเรื่องที่เกี่ยวกับระบบน้ำมีอะไรบ้าง (สุขภาพ, เครื่องใช้ไฟฟ้าเสียหาย ฯลฯ)?
5. เราวางแผนที่จะสัมภาษณ์ชาวบ้าน มีอะไรที่เราควรจะตระหนักถึงเมื่อสอบถามแบบตัวต่อตัว
6. เราสามารถสัมภาษณ์ผู้หญิงได้ไหม

เศรษฐศาสตร์

7. ขณะนี้ชาวบ้านได้เสียค่าใช้จ่ายเกี่ยวกับระบบน้ำให้ PDA หรือเปล่า (น้ำจากปั๊ม น้ำจากแท้งก์)ถ้าหากมีค่าใช้เราขอทราบได้ไหมว่าค่าใช้จ่ายเท่าไหร่

เทคนิค

8. คุณช่วยอธิบายการลำเลียงของน้ำ จากน้ำบาดาลในบ่อจนไปถึงบ้านผู้ใช้น้ำได้หรือไม่?
9. ขณะนี้ได้มีขั้นตอนการดำเนินการบำรุงรักษาใด ๆ ในระบบบ้างหรือเปล่า?
    a. หากมี ใครเป็นผู้ปฏิบัติ?
    b. บ่อยแค่ไหน?
    c. ขั้นตอนเป็นอย่างไร?
10. ได้มีการจดบันทึกคุณภาพของน้ำ หรือการบำรุงรักษาระบบ ที่เราสามารถขอดูได้ไหม?

คำถามเพิ่มเติม

11. คุณมีข้อมูลเพิ่มเติมใด ๆ ที่อาจจะสามารถปรับปรุงความเข้าใจของเราเกี่ยวกับปัญหานี้หรือไม่?
12. คุณสามารถให้ข้อมูลการติดต่อของผู้เชี่ยวชาญที่อาจช่วยให้ความเข้าใจของเราของโครงการนี้เช่นผู้เชี่ยวชาญด้านคุณภาพน้ำหรือวิศวกรโยธา?
13. มีที่ที่ใกล้กับกระบี่ที่เราสามารถดำเนินการทดสอบตัวอย่างน้ำที่เราเก็บรวบรวมมาได้ไหม?

ขอบพระคุณที่สละเวลาครับ/ค่ะ ทางเรายินดีที่ได้รับทราบข้อเท็จจริงและความคิดเห็นของคุณ

Appendix F: Department of Groundwater Resources Acceptable Standards of Water Properties (Project Team's Testing Parameters)

Physical properties

List	Appropriate value	Maximum value
Color	5 (platinum-cobalt scale)	15 (platinum-cobalt scale)
Turbidity	5 (NTU)	20 (NTU)
pH	7.0-8.5	6.5-9.2

Chemical properties

List	Appropriate value(mg/L)	Maximum value (mg/L)
Iron (Fe)	<0.5	1
Manganese (Mn)	<0.3	0.5
Copper (Cu)	<1.0	1.5
Zinc (Zn)	<5.0	15
Sulfate (SO_4)	<200	250
Chloride (Cl)	<250	600
Fluoride (F)	<0.7	1.0
Nitrate (NO_3)	<45	45
Total hardness as $CaCO_3$	<300	500
Non-carbonate hardness as $CaCO_3$	<200	250
Total dissolved solids	<600	1,200

Appendix G: T-Tech Water Treatment Company Quality Results

Date: 15 November 2014

Sanam Geela (A1)

Depth 33 m, flow rate 8 m^3/hr, supplies to 68 households.

List	Result	Standard Values from Ministry of Natural Resources and Environment (Drinking Standard)	Standard Values from Ministry of Public Health (Drinking Standard)
pH	7.2	7.0-8.5	6.5-8.5
Total Iron	0.05 ppm	<0.5 ppm	<0.3 ppm
Chloride Ion	60 ppm	<250 ppm	<250 ppm
Total Hardness	200 ppm	<300 ppm	<100 ppm
Total Solid	220 ppm	<600 ppm	<500 ppm

Hua Kuan Tha Glang (A2)

Depth 43 m, flow rate 10 m^3/hr, supplies to 120 households

List	Result	Standard Values from Ministry of Natural Resources and Environment (Drinking Standard)	Standard Values from Ministry of Public Health (Drinking Standard)
pH	7.2	7.0-8.5	6.5-8.5
Total Iron	0.05 ppm	<0.5 ppm	<0.3 ppm
Chloride Ion	40 ppm	<250 ppm	<250 ppm
Total Hardness	100 ppm	<300 ppm	<100 ppm
Total Solid	150 ppm	<600 ppm	<500 ppm

Sam Yak Klong Kruad (A3)

Depth 28 m, flow rate 5 m^3/hr, supplies to 35 households.

List	Result	Standard Values from Ministry of Natural Resources and Environment (Drinking Standard)	Standard Values from Ministry of Public Health (Drinking Standard)
pH	7.5	7.0-8.5	6.5-8.5
Total Iron	0.05 ppm	<0.5 ppm	<0.3 ppm
Chloride Ion	40 ppm	<250 ppm	<250 ppm
Total Hardness	50 ppm	<300 ppm	<100 ppm
Total Solid	35 ppm	<600 ppm	<500 ppm

Klong Kruad (A4) before treatment

Depth 110 m, flow rate 24 m^3/hr, supplies to 107 households.

List	Result	Standard Values from Ministry of Natural Resources and Environment (Drinking Standard)	Standard Values from Ministry of Public Health (Drinking Standard)
pH	7.0	7.0-8.5	6.5-8.5
Total Iron	3.5 ppm	<0.5 ppm	<0.3 ppm
Chloride Ion	40 ppm	<250 ppm	<250 ppm
Total Hardness	250 ppm	<300 ppm	<100 ppm
Total Solid	345 ppm	<600 ppm	<500 ppm

Chong Kao (B1)

List	Result	Standard Values from Ministry of Natural Resources and Environment (Drinking Standard)[1]	Standard Values from Ministry of Public Health (Drinking Standard)[2]
pH	6.0	7.0-8.5	6.5-8.5
Total Iron	0.05 ppm	<0.5 ppm	<0.3 ppm
Chloride Ion	40 ppm	<250 ppm	<250 ppm
Total Hardness	100 ppm	<300 ppm	<100 ppm
Total Solid	75 ppm	<600 ppm	<500 ppm

Appendix H: Transcribed Interview with Director of Krabi PDA, Khun Aumnuay

Chair: Atichart
Secretary: Kamolvara
Attendees: Panida, Walrisara, Nathan, Joseph, Sebastian, Camden, Aj.Bob and Khun Aumnuay

Schedule:

- **Describe about observations made in the two villages on first day of work.**
- **Explain villager's perception of problem according to the surveys conducted on second day of work.**
- **Perform an interview with Khun Aumnuay according to Appendix E1 and E2. Questions include the following:**

General Questions:

1. Please explain the current situation in Baan Tha Thong Lang and Baan Tha Lane.
    A. *Baan Tha Thong Lang's problem is some of villagers don't willing to use water because of water quality.*
    B. *Baan Tha Lane's problem is about water scarcity.*
2. After speaking with members of the PDA in Bangkok, our understanding of this project is that these two villages present two different problems related to their water system and we are to analyze both of them for damage and poor water quality, ask the villagers for problems currently faced by them related to the systems and report back to the PDA on our discoveries as well as recommended treatment methods and even create a budget for our recommendations.
    Do you agree with this goal? If not, can you please guide us as to what your expectations are for us?
    A. *Khun Aumnuay does agree with the goal, however we would need to add another topic to the recommendation which was to change the perception of the villagers in Baan Tha Lane to be willing to accept PDA's offer of help.*
3. Do you perceive any hurdles that could hinder the success of this assignment for our team?
    A. *Khun Aumnuay added one concern to Baan Tha Lane about the perception of the villager's towards the PDA and the local government. The fact that the local government had provided cheaper water systems but are not as good as the PDA's proposed system could make the villagers feel uneasy to risk paying for PDA's water system.*
    B. *Baan Tha Thong Lang have problem about belief of villagers which should be improved about business of water system because PDA and the government didn't close to each other, so it's problematic for PDA to get help from government.*

Social Questions:

4. What are some examples of issues the villagers from both villages are experiencing in regards to the water systems (health, damaged appliances, etc.)?
    A. *In Baan Tha Lane, there are issues about inconvenient living due to lack of water.*

B. *In Baan Tha Thong Lang, there are issues about the quality of water supply which are currently not drinkable.*

5. We are planning on conducting interviews with the villagers, is there anything we should be aware of when speaking one-on-one with people?
   A. *Politics and religious topics should be avoided during discussion.*
6. Is it appropriate for us to interview women?
   A. *There are no problems to interview women in the villages, but appointments should be made in prior.*

Economic Questions:

7. Are the villagers currently paying for the services the PDA is providing through the well system? (E.g. water to the home appliances, water from the tanks, etc.) If yes, may we ask how much they are paying?
   A. *No, PDA did not provide any facilities in Baan Tha Lane and Baan Tha Thong Lang.*

Technical Questions:

8. Can you explain to us the layout of the systems from the aquifer to the households?
   A. *Water pumped from the wells flow to the storage tanks, then it goes through filtration and gets distributed to the villagers' houses.*
9. Are there currently any maintenance procedures performed on the systems?
   A. *PDA did not provide anything for both of villages yet since the water systems are currently responsible by the local government, therefore maintenance are not performed by PDA.*
   a. If so, who does them?
      A. *The local government.*
   b. If so, how often?
      A. *He has no idea about this since the local government would not be pleased if PDA tried to merge into their work.*
   c. If so, what is the procedure?
      A. *He has no idea about this since the local government would not be pleased if PDA tried to merge into their work.*
10. Do you have maintenance and/or water quality records we can have access to?
    A. *He gave us a water testing results of Baan Tha Thorng Lang including pH test, total dissolved solid, iron composition, chloride composition and total hardness.*

Additional Questions:

11. Is there any additional information you may able to provide to improve our understanding of this problem?
    A. *He want us to go to see the site, so we can understand clearer about the problems of villages.*
12. Could you provide us with any contact information of specialists that may help our understanding of this project, such as water quality experts or civil engineers?
    A. *We can contact to the local government because they have staffs who have dealt with the real systems in the area of the two villages.*
13. Are there any places near Krabi City where we could perform tests on any water samples we collect here?
    A. *TTEC Company, Krabi.*

Appendix I: Test report for Hua Kuan Tha Klang well (A1)

Food Research and Testing Laboratory
Faculty of Science Chulalongkorn University
Floor 16th Mahamakut Building Phayathai Road,
Pathumwan, Bangkok 10330, Thailand

Report No. : C 0015/15
Issued Date: 13 February 2015
Sample ID : 150253

---------- begin report ----------

Test Report

Client Name : The rotary club of Bangkok

Client Address : The rotary club of Bangkok

Sample Description : Huakuanthaklang /Water packed in close plastic bottle
Net volume 4 L. approx.

Sampling by : Client

Date Sample Received : 29 January 2015

Date Analyzed : 29 January 2015

Test Results

Test items	Test Results	Test Method	Limit of detection
Iron (Fe)	0.050 mg/L	APHA,AWWA,WEF(2012)3120B,3030E	-
Manganese (Mn)	0.069 mg/L		-
Copper (Cu)	Not detected		0.006 mg/L
Zinc (Zn)	0.028 mg/L		-
Fluoride (F)	Not Detected	In-house method based on APHA, AWWA, WEF(2012) 4500-F^- D.	0.10 mg/L
Chloride (Cl)	6.95 mg/L	APHA,AWWA,WEF(2012) 4500-Cl^-B.	-
Nitrate (NO_3-N)	< 0.50 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-NO_3^- E.	-
Sulphate (SO_4)	8.65 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-SO_4^{2-} E.	-
Total Hardness	108.08 mg/ L	APHA,AWWA,WEF(2012) 2340A.	-
Total Dissolved Solids	173.00 mg/ L	APHA,AWWA,WEF(2012) 2540C.	-
Conductivity	230.00 µS/cm	In-house method based on APHA, AWWA, WEF(2012) 2510 B.	-
Turbidity	0.58 NTU	In-house method based on APHA, AWWA, WEF(2012) 2130 B.	-
Color	0.37 Pt-Co Unit	In-house method based on APHA, AWWA, WEF(2012) 2120 C.	-

Remark : -

---------- end report ----------

Approved By

(Phattarapanyakul, Wilai)
Technician Manager,
Chemical Laboratory

(Tantratian, Sumet Assoc. Prof. Dr)
Deputy Director

(Kokpol, Sirirat Assoc. Prof. Dr)
Director

F-QM-0032/R02

Appendix J: Test Report for Sanam Geela Well (A2)

Food Research and Testing Laboratory
Faculty of Science Chulalongkorn University
Floor 16th Mahamakut Building Phayathai Road,
Pathumwan, Bangkok 10330, Thailand

Report No. : C 0016/15
Issued Date: 13 February 2015
Sample ID : 150254
Page 1 of a total of 1 pages

---------- begin report ----------

Test Report

Client Name : The rotary club of Bangkok

Client Address : The rotary club of Bangkok

Sample Description : Sanam Geela /Water packed in close plastic bottle
Net volume 4 L. approx.

Sampling by : Client

Date Sample Received : 29 January 2015

Date Analyzed : 29 January 2015

Test Results

Test items	Test Results	Test Method	Limit of detection
Iron (Fe)	Not detected	APHA,AWWA,WEF(2012)3120B,3030E	0.007 mg/L
Manganese (Mn)	Not detected		0.002 mg/L
Copper (Cu)	Not detected		0.006 mg/L
Zinc (Zn)	0.035 mg/L		-
Fluoride (F)	Not detected	In-house method based on APHA, AWWA, WEF(2012) 4500-F^- D.	0.10 mg/L
Chloride (Cl)	4.66 mg/L	APHA,AWWA,WEF(2012) 4500-Cl^-B.	-
Nitrate (NO_3-N)	<0.50 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-NO_3^- E.	-
Sulphate (SO_4)	7.18 mg/ L	In-house method based on APHA, AWWA, WEF(2012) 4500-SO_4^{2-} E.	-
Total Hardness	235.26 mg/ L	APHA,AWWA,WEF(2012) 2340A.	-
Total Dissolved Solids	267.50 mg/ L	APHA,AWWA,WEF(2012) 2540C.	-
Conductivity	448.50 µS/cm	In-house method based on APHA, AWWA, WEF(2012) 2510 B.	-
Turbidity	0.22 NTU	In-house method based on APHA, AWWA, WEF(2012) 2130 B.	-
Color	0.56 Pt-Co Unit	In-house method based on APHA, AWWA, WEF(2012) 2120 C.	-

Remark : -

---------- end report ----------

Approved By

(Phattarapanyakul, Wilai)
Technician Manager,
Chemical Laboratory

(Tantratian, Sumet Assoc. Prof. Dr)
Deputy Director

(Kokpol, Sirirat Assoc. Prof. Dr)
Director

F-QM-0032/R02

Appendix K: Test Report for Sam Yak Klong Kruad Well (A3)

Food Research and Testing Laboratory
Faculty of Science Chulalongkorn University
Floor 16th Mahamakut Building Phayathai Road,
Pathumwan, Bangkok 10330, Thailand

Report No. : C 0017/15
Issued Date: 13 February 2015
Sample ID : 150255

---------- begin report ----------

Test Report

Client Name : The rotary club of Bangkok

Client Address : The rotary club of Bangkok

Sample Description : Samyakklongkruad /Water packed in close plastic bottle
Net volume 4 L. approx.

Sampling by : Client

Date Sample Received : 29 January 2015

Date Analyzed : 29 January 2015

Test Results

Test items	Test Results	Test Method	Limit of detection
Iron (Fe)	Not detected	APHA,AWWA,WEF(2012)3120B,3030E	0.007 mg/L
Manganese (Mn)	0.086 mg/L		-
Copper (Cu)	0.007 mg/L		-
Zinc (Zn)	0.017 mg/L		-
Fluoride (F)	Not detected	In-house method based on APHA, AWWA, WEF(2012) 4500-F^- D.	0.10 mg/L
Chloride (Cl)	5.34 mg/L	APHA,AWWA,WEF(2012) 4500-Cl^-B.	-
Nitrate (NO_3-N)	2.45 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-NO_3^- E.	-
Sulphate (SO_4)	7.76 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-SO_4^{2-} E.	-
Total Hardness	10.81 mg/ L	APHA,AWWA,WEF(2012) 2340A.	-
Total Dissolved Solids	42.50 mg/ L	APHA,AWWA,WEF(2012) 2540C.	-
Conductivity	57.70 µS/cm	In-house method based on APHA, AWWA, WEF(2012) 2510 B.	-
Turbidity	0.12 NTU	In-house method based on APHA, AWWA, WEF(2012) 2130 B.	-
Color	Not detected	In-house method based on APHA, AWWA, WEF(2012) 2120 C.	0.10 Pt-Co Unit

Remark : -

---------- end report ----------

Approved By

(Phattarapanyakul, Wilai)	(Tantratian, Sumet Assoc. Prof. Dr)	(Kokpol, Sirirat Assoc. Prof. Dr)
Technician Manager, Chemical Laboratory	Deputy Director	Director

F-QM-0032/R02

Appendix L: Test Report for Klong Kruad Well (A4)

Food Research and Testing Laboratory
Faculty of Science Chulalongkorn University
Floor 16th Mahamakut Building Phayathai Road,
Pathumwan, Bangkok 10330, Thailand

Report No. : C 0018/15
Issued Date: 13 February 2015
Sample ID : 150256
Page 1 of a total of 1 pages

---------- begin report ----------

Test Report

Client Name : The rotary club of Bangkok

Client Address : The rotary club of Bangkok

Sample Description : Klongkruad /Water packed in close plastic bottle
Net volume 4 L. approx.

Sampling by : Client

Date Sample Received : 29 January 2015

Date Analyzed : 29 January 2015

Test Results

Test items	Test Results	Test Method	Limit of detection
Iron (Fe)	0.195 mg/L	APHA,AWWA,WEF(2012)3120B,3030E	-
Manganese (Mn)	0.059 mg/L		-
Copper (Cu)	Not detected		0.006 mg/L
Zinc (Zn)	0.021 mg/L		-
Fluoride (F)	0.27 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-F^- D.	-
Chloride (Cl)	5.44 mg/L	APHA,AWWA,WEF(2012) 4500-Cl^-B.	-
Nitrate (NO_3-N)	Not detected	In-house method based on APHA, AWWA, WEF(2012) 4500-NO_3^- E.	0.05 mg/L
Sulphate (SO_4)	55.60 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-SO_4^{2-} E.	-
Total Hardness	374.01 mg/ L	APHA,AWWA,WEF(2012) 2340A.	-
Total Dissolved Solids	405.00 mg/ L	APHA,AWWA,WEF(2012) 2540C.	-
Conductivity	708.00 µS/cm	In-house method based on APHA, AWWA, WEF(2012) 2510 B.	-
Turbidity	0.94 NTU	In-house method based on APHA, AWWA, WEF(2012) 2130 B.	-
Color	1.11 Pt-Co Unit	In-house method based on APHA, AWWA, WEF(2012) 2120 C.	-

Remark : -

---------- end report ----------

Approved By

(Phattarapanyakul, Wilai)
Technician Manager,
Chemical Laboratory

(Tantratian, Sumet Assoc. Prof. Dr)
Deputy Director

(Kokpol, Sirirat Assoc. Prof. Dr)
Director

F-QM-0032/R02

Appendix M: Test Report for Baan Chong Kao Well (B1)

Food Research and Testing Laboratory
Faculty of Science Chulalongkorn University
Floor 16th Mahamakut Building Phayathai Road,
Pathumwan, Bangkok 10330, Thailand

Report No. : C 0019/15
Issued Date: 13 February 2015
Sample ID : 150257
Page 1 of a total of 1 pages

---------- begin report ----------

Test Report

Client Name : The rotary club of Bangkok

Client Address : The rotary club of Bangkok

Sample Description : Thalane /Water packed in close plastic bottle
Net volume 4 L. approx.

Sampling by : Client

Date Sample Received : 29 January 2015

Date Analyzed : 29 January 2015

Test Results

Test items	Test Results	Test Method	Limit of detection
Iron (Fe)	Not detected	APHA,AWWA,WEF(2012)3120B,3030E	0.007 mg/L
Manganese (Mn)	0.043 mg/L		-
Copper (Cu)	Not detected		0.006 mg/L
Zinc (Zn)	0.030 mg/L		-
Fluoride (F)	0.13 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-F^- D.	-
Chloride (Cl)	4.30 mg/L	APHA,AWWA,WEF(2012) 4500-Cl^-B.	-
Nitrate (NO_3-N)	1.34 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-NO_3^- E.	-
Sulphate (SO_4)	9.75 mg/L	In-house method based on APHA, AWWA, WEF(2012) 4500-SO_4^{2-} E.	-
Total Hardness	67.86 mg/ L	APHA,AWWA,WEF(2012) 2340A.	-
Total Dissolved Solids	85.50 mg/ L	APHA,AWWA,WEF(2012) 2540C.	-
Conductivity	152.40 µS/cm	In-house method based on APHA, AWWA, WEF(2012) 2510 B.	-
Turbidity	0.16 NTU	In-house method based on APHA, AWWA, WEF(2012) 2130 B.	-
Color	Not detected	In-house method based on APHA, AWWA, WEF(2012) 2120 C.	0.10 Pt-Co Unit

Remark : -

---------- end report ----------

Approved By

(Phattarapanyakul, Wilai)	(Tantratian, Sumet Assoc. Prof. Dr)	(Kokpol, Sirirat Assoc. Prof. Dr)
Technician Manager, Chemical Laboratory	Deputy Director	Director

F-QM-0032/R02

Appendix N: Costs for Chemical Precipitation

*** Please note that all numbers used in the following tables were taken directly from http://www.dgr.go.th/project_kpn/file/2553/pdf5303.1.pdf***

Table 1: Cost for electricity (average of 4 Baht per unit)

No.	List of Equipment	Usage (Hours per day)	Amount	Electricity consumption (kW)	Energy consumption (Days)	Price per day (Baht)
1	Feed pump	14	1	4	56	224
2	Centrifugal pump	14	1	1.5	21	84
3	Chemical fluid pump	14	2	0.18	2.52	20.16
Total cost for electricity (Baht per day)						**328.16**
Total cost for electricity (Baht per m^3)						**2.73**

Table 2: Cost of chemicals

No.	List of Equipment	Quantity (ml per min)	Amount per day (kg)	Price per unit (Baht)	Price per day (Baht)
1	Sodium Carbonate	2	0.144	20	2.88
2	Carbonate	2	0.144	13	1.87
Total cost for chemicals (Baht per day)					**4.75**
Total cost for chemicals (Baht per m^3)					**0.04**

Table 3: Cost for maintenance

No.	List of Equipment	Life-span (Year)	Amount	Price per unit (Baht)	Price per day (Baht)
1	Spare parts for feed pump	5	1	8,000	4.38
2	Spare parts for centrifugal pump	5	1	8,560	4.69
3	Spare parts for chemical	5	1	5,000	2.74

	fluid pump				
4	Sand filter	1	0.4 m^3	5,000	5.48
5	Circuit breaker	5	bulk	10,000	5.48
Total cost for maintenance (Baht per day)					**22.77**
Total cost for maintenance (Baht per m^3)					**0.20**

Table 4: Budget for implementing chemical precipitation

Breakdown	Cost (Baht)
Build and Installation Fee	150,000 - 190,000
Operating Cost (per m^3)	2.97

Appendix O: Costs for Ion Exchange

Table 5: Cost for electricity (average of 4 Baht per unit)

No.	List of Equipment	Usage (Hours per day)	Amount	Electricity consumption (kW)	Energy consumption (Days)	Price per day (Baht)
1	Feed pump	14	1	4	56	224
2	Centrifugal pump	14	1	1.5	21	84
Total cost for electricity (Baht per day)						**308.00**
Total cost for electricity (Baht per m^3)						**2.57**

Table 6: Cost for chemicals

No.	List of Equipment	Quantity (ml per min)	Amount per day (kg)	Price per unit (Baht)	Price per day (Baht)
1	Sodium Chloride	2	0.144	13	1.87
Total cost for chemicals (Baht per day)					**61.87**
Total cost for chemicals (Baht per m^3)					**0.52**

Table 7: Cost for maintenance

No.	List of Equipment	Life-span (Year)	Amount	Price per unit (Baht)	Price per day (Baht)
1	Spare parts for feed pump	5	1	8,000	4.38
2	Spare parts for centrifugal pump	5	1	8,560	4.69
3	Circuit Breaker	5	bulk	10,000	5.48
4	Resin	2	bulk	20,000	27.40
Total cost for maintenance (Baht per day)					**41.95**
Total cost for maintenance (Baht per m^3)					**0.30**

Table 8: Budget for implementing ion exchange

Breakdown	Cost (Baht)
Build and Installation Fee	135,000 - 165,000
Operating Cost (per m^3)	3.39

Appendix Q: Budget sheet for digging a new well in Krabi Province

Estimated costs for drilling a new well system, which is based on data from Konginpaan, P. (Ed.). (2014, February 6). Estimated Cost for Digging a Well in Baan Khlong Yirae Moo13 Krabi.

List	Amount	Unit	Price of Material		Wage		Total
			Per unit	Total price	Per unit	Total price	
Constructing 80 meters well							
Conductor pipe PVC 6in. Diameter	14	pipe	1915	26810	239	3346	30156
Filter pipe PVC 6in. Diameter	5	pipe	1915	9575	239	1195	10770
Sedimental pipe PVC 6in. Diameter	1	pipe	1915	1915	239	239	2154
Suck pipe PVC 2in. Diameter	18	pipe	187	3366			3366
GS pipe 2in. Diameter	1	pipe	1143	1143			1143
Union 2in Diameter	1		95	95			95
Nipple 2in. Diameter	2		37	74			74
Brass valve	1	set	350	350			350
Blade Switch	1		69	69			69
Steel wire rope	80	meter	30	2400			2400
90 degree elbow	2		48	96			96
Brass water gate	1	set	1728	1728			1728
PVC pipe 2in. Diameter	1		197	187			187
Connector waterproof aluminum	1		170	170			170
Rigid Steel Conduit 3/4in.	4	meter	15	60			60
Waterproof electrical line	80	meter	54	4320			4320
Sand and gravel filter	2.7	cub.	2000	5400	500	1350	675

		m.					0
Scientific mud	6	bags	850	5100			5100
Concrete	1	L/S	2500	2500			2500
Fuel	540	Liter	31	16470			16470
Wage for drilling well	80	meter			850	68000	68000
Wage for well cleaning	1				5000	5000	5000
Wage for water quantity testing	1				2000	2000	2000
Wage for water quality testing	1				5000	5000	5000
Implanting the pump							
Pump Submersible 1.5Kilowatt	1	machine	17000	17000			17000
Pump controller	1	machine	6500	6500			6500
Installation of low voltage							
electricity post at least 8m. Tall	2	post	1500	3000			3000
electricity line aluminum at least 25 millimeter wide	70	meter	25	1750			1750
wire connector	1		1750	1750			1750
Electricity Meter of 15A	1	set	1500	1500			1500
Total Cost **199,458**							

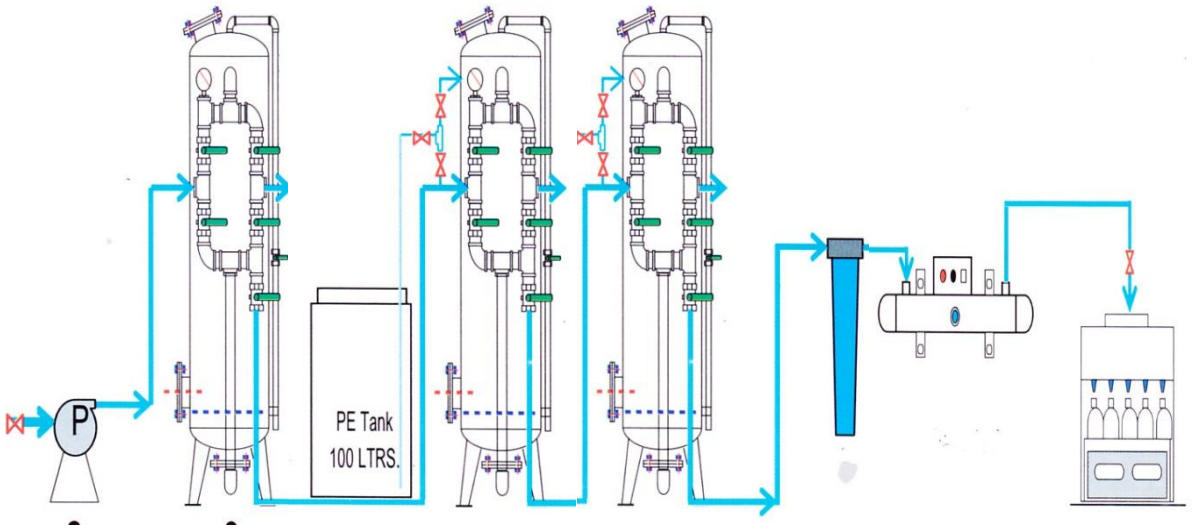
Appendix R: Summary of budget for solutions in Baan Tha Lane

First Water System Configuration		
	Price (baht)	
Well depth	**50m**	**130m**
Digging a new well (with groundwater pump)	127,500	331,500
100m pipe system (with labor)	20,167	20,167
Extra costs	40,000	40,000
Total	**187,667**	**391,667**

Second Water System Configuration		
	Price (baht)	
Well depth	**50m**	**130m**
Digging a new well (with groundwater pump)	127,500	331,500
1200m pipe system (with labor)	242,000	242,000
Extra costs	40,000	40,000
Total	**409,500**	**613,500**

Third Water System Configuration		
	Price (baht)	
Well depth	**50m**	**130m**
Digging a new well (with groundwater pump)	127,500	331,500
1200m pipe system (with labor)	242,000	242,000
30m^3 storage tank	616,000	616,000
Extra costs	40,000	40,000
Total	**1,025,500**	**1,229,000**

Appendix S: Softener Water Filtration System Model, FCU-8. (From Tipmaneerat Products)



1 2 3 4 5 6

Model. FCU-8 Capacity 900 L / hr.

System Includes.

1. Automatic pump
2. Anthracite filter
3. Softener)Cation Resin (
4. Activated Carbon filter
5. Cartridges Ceramic filters
6. UV.)Ultraviolet System(

@ Total Cost of Water Filtration System 58,000 Baht.

Softener Ultraviolet System

Water quality can be filtered.

Maximum pressure	:	150 psi.
pH scope	:	6.5 – 9.2
Total Hardness	:	< 300 mg./L.
Total dissolved solids	:	< 1,200 mg./L.
Turbidity	:	< 20

PROCESS DESCRIPTION

The Multimedia filter is pretreatment system used for colloidal particle, organic and chlorine removal from Ultraviolet feed water.

The Softener is pretreatment system used for hardness removal from Ultraviolet feed water.

Water Filtration System
EQUIPMENT SPECIFICATION
KUK - FCU 8) 900 L / h. (

1. Automatic pump

Q'ty	:	1 Set
Type	:	Centrifuqal
Capacity	:	40-50 L./m.
Model	:	Walrus TP820
Motor	:	370 W. 220 V. 50 Hz.

2. Anthracite filter

Q'ty	:	1 Set
Capacity	:	1600 L./h.
Type	:	Vertical Cylindrical
Size	:	Diameter 200 mm. Hight 1200 mm.
Material	:	Stainless Steel 304 Thickness 1.5 mm.
Filter Media	:	Anthracite 25 liters
Piping	:	Ø 3/4" PVC
Value	:	Ball Valves ¾'' PVC
Operation	:	Manual
Removal	:	Iron, Manganese, Decolourization, Dechlorination, Deodorization,and removal of organic compound in water

3. Softener

Q'ty	:	1 Set
Capacity	:	1600 L. /h.
Type	:	Vertical Cylindrical
Size	:	Diameter 200 mm.

Height 1200 mm.

Material : Stainless Steel 304 Thickness 1.5 mm
Filter Media : Cation Resin 25 L
Piping : Ø 3/4" PVC
Valve : Ball Valves ¾" PVC
Operation : Manual
Removal : Limestone, Cadmium, Sulfate, Magnesium.

4. Activated Carbon filter

Q'ty : 1 Set
Capacity : 1600 L. / h.
Type : Vertical Cylindrical
Size : Diameter 200 mm.
Height 1200 mm.
Material : Stainless Steel 304 Thickness 1.5 mm.
Filter Media : Activeted Carbon 25 liters
Piping : Ø 3/4" PVC
Valve : Ball Valves ¾" PVC
Operation : Manual
Removal : Organic, Dechlorination, Decolourization

5. Cartridges Ceramic filters

Q'ty : 2 sets.
Removal : Ceramic filter about 0.3-0.9 micron as Microfiltration
Capacity : 900 L. / h.

6. Ultraviolet

Q'ty : 1 Set
Material : Stainless Steel 304
Energy required : 220 VAC / 15 watts
Capacity : 1500 L. / h.
Removal : Virus , Bacteria

7. Piping & Installation

Q'ty : 1 Set
Material : PVC
Area : 4.0 m. Ø 3/4"From Automatic Pump, Anthracite filter, Activated Carbon filter, Softener ,Cartridges Ceramic filters to Ultraviolet.

Total Maintenance Cost of Filtration System 9,600 Baht.

1. Anthracite filter

Routine maintenance : backwash by water 1-2 time a week.
) No need any chemical for backwash (
Replacement cost : about 2 years.
: about 1,900 baht / time.

.2 Carbon filter

Routine maintenance : backwash by water 1-2 time a week.
)No need any chemical for backwash.(
Replacement cost : about 2 years.
: about 2,000 baht / time.

3 . Softener
Routine maintenance : backwash by salt water 1 time a month.
)No need any chemical for backwash.(
Replacement cost : about 2 years.
: about 2,500 baht / time.

4. Ceramic filters
Routine maintenance : wash by water 1 time a month.
)No need any chemical for backwash.(
Replacement cost : about 6 months.
: about 1,200 baht / time.

5. Ultraviolet Lamp
Routine maintenance : wash by water 1 time a year.
) No need any chemical for wash.(
Replacement cost : about 8,000 hour.
: about 2,000 baht / time.

Appendix T: Water Sample Procedures

Procedure for pH Testing

1. Fill and rinse a glass container of 500 ml three times to ensure no outside contaminants exist in the water.
2. Fill the 500 ml glass container fully to ensure the pH meter is submersed in water.
3. Fully insert the pH meter into a glass container so that the tip of the meter is fully submersed in the water.
4. Swirl the pH meter in the water for one minute.
5. At the one minute mark, press the "Hold" button and record the result.

Procedure for Water Sample Collection

1. Rinse each bottle three times to ensure no outside contaminants exist in the water sample.
2. Fill the bottle fully to ensure the proper amount of water is provided for the water quality testing.
3. Cover the bottle with Parafilm to ensure the water sample is not contaminated while being transported to the laboratory.
4. Fill an additional bottle* halfway and seal with Parafilm to ensure the water sample is not contaminated while being transported to the lab.
5. Place all samples in a Styrofoam container and add ice to ensure samples remain at 4^{0}C.

* We filled the additional bottle only half way to save weight and use as a spare amount of water in case the laboratory technicians needed more water for testing.

Procedure for Dropping Nitric Acid in Water Samples

1. Place latex glove on hands to ensure acid does not touch skin.
2. Remove parafilm from the bottle container and open the lid to the bottle.
3. Add 2 milliliters of nitric acid to the bottle container.
4. Seal the bottle caps with parafilm.