# Local Water Network Rectification in Krabi, Thailand

An Interactive Qualifying Project submitted to the Faculty of
Worcester Polytechnic Institute in partial fulfillment of the requirements for the
Degree of Bachelor of Science in cooperation with Chulalongkorn University


**Submitted by:**
Nathan Alvord
Camden Knoff
Joseph Lidwin
Sebastian Ortiz


**Submitted to:**
Khun Jood, PDA

**Project Advisors:**
Professor Bob Kinicki, WPI
Professor Fabienne Miller, WPI

## Authorship Page

Nathan wrote the majority of the Background chapter. Sebastian and Camden wrote the Methodology chapter. Joseph wrote the Introduction chapter. In its final form, this report contains equal contributions from all group members, and each section represents the collaborative effort of multiple authors.

## Abstract

Many communities along the western coast of Thailand including Baan Tha Lane and Baan Tha Thong Lang were devastated by the 2004 Indian Ocean Tsunami. Since then, the Population and Community Development Association (PDA) has built a replacement water distribution system for these two villages. Poor water quality is damaging the pipes, pumps, and household appliances connected to this water system. The goal of this project is to develop a set of recommendations for the PDA that outline feasible water treatment methods for the system. We will gather information from the people who use the system, input from knowledgeable experts, and data from water quality testing to accomplish this goal. Finally we will use a ranking metric to create a set of feasible recommendations for the PDA.

**Table of Contents**

**List of Figures**



**List of Tables**

# 1. INTRODUCTION

According to the United Nations, 6 to 8 million people die annually from the consequences of water-related diseases, which is largely an effect of clean water scarcity (United Nations, 2013). Quality water, or clean water, is hard to define quantitatively, but rather is a term that we will use to describe water that can be consumed or utilized without major physical repercussions to the people, agriculture, or distribution network involved. Areas lacking high quality water affect residents because the water supplied to them cannot be used for drinking, cooking, cleaning, farming, or other daily activities. Roughly 780 million people are living in areas where clean water is not accessible (United Nations, 2013). These people must instead utilize water containing hard metals, pesticides, or other contaminants. Consumption of such water can cause individuals to develop health issues such as heart diseases, malnourishment, and weak immune systems (Riley, 2011). A lack of quality water not only contributes to poor health, but can have negative effects on infrastructure as well. Pipes, pumps, wells, and other items that interact with poor quality water can become damaged (Diersing, 2009). This deterioration of property puts further strain on communities afflicted with water related issues.

Water quality degradation is so severe in many Asian countries that it is placing serious constraints on economic growth, e.g., in Thailand where 71 percent of its water demand goes towards the agricultural sector (FAO, 2000). Crops demand a certain quality of water in order to receive proper nutrients and promote healthy growth, which many rural areas of southern Thailand do not have access to. Over one third of Thailand's surface water is considered of poor quality, which is most prevalent in the southern region of the country (Suwal, 2014). In order to gain access to better quality water, Thailand has water systems that draw their water from underground sources, such as aquifers. Public groundwater sources account for 75% of the Thai population's household water supply, serving approximately 35 million people in villages and in urban areas (FAO, 2000). Without treatment, these important sources of water do not reach acceptable water quality levels for agricultural and domestic purposes. The residents of villages in southern Thailand rely on these underground water sources but are limited by a lack of adequate water quality for their everyday lives.

Impurities caused by minerals and chemicals in the ground are negatively impacting the water quality in the aquifers that villages in southern Thailand rely on to sustain life. High levels of sodium and chloride seep into the water that the villagers drink and use for agricultural purposes (Saraphirom, 2013). In Thailand, it is estimated that 10% of all the land used for irrigation, approximately 80,000 square miles, is affected by salinity contamination (Ghassemi, 1995). These contaminants along with high alkalinity and other undesirable solutes are the result of both human and environmental factors. The chemical composition of the contaminants is damaging the water distribution systems by blocking flow through the building up of mineral deposits in pipes. Additionally, these contaminants are also causing corrosion to the piping material (Marcoux, 2005). The results of these contaminants are leading to damage and destruction of water systems that are the only method for communities to have a constant water supply.

The Thai government is spending millions of dollars to try and slow down the rate of water contamination and reclaim the land that is high in salinity. However, these efforts are not reaching all of the rural villages in Thailand (Thies et all, 1999). To address a problem like this, it is important to know what types of contaminates are present, what are the sources of these contaminants and how they affect the infrastructure of the system. Such criteria should be verified based on the response of individual organisms, their populations, and communities to the effect of pollutants (Wang, 2013). To develop a full understanding of the issues with a water system, establishing the social, economic, and technical issues surrounding the water system is necessary in developing the full scope of the problem.

The villages of Baan Tha Lane and Baan Tha Thong Lang in Thailand's southern province of Krabi face a water quality crisis due to a large tsunami that struck the area in 2004. The goal of this project is to aid two villages in Krabi by addressing the socially important problem of substandard living conditions due to damaged pipes and pumps caused by poor water quality in the area. We will ascertain sources of information from a variety of methods that allow us to determine how the quality of water is currently affecting the villagers in Krabi. These methods will include collecting qualitative data through surveys of villagers and interviews with local water experts to define the social concerns associated with the PDA's water distribution network. Our team will also collect quantitative data in the form of water property testing to enable us to properly address the technical challenges the water creates for the water system. Through the combination of evaluating our quantitative and qualitative data, our team will be able to properly identify the major concerns with the system and be able to provide a list of recommendation criteria for the Public Community Development Association to use on future improvements.

# 2. BACKGROUND

Before developing an action plan that effectively addresses water quality in Krabi, our project team needed to research the local water situation and learn more about water quality issues. This chapter will discuss the definition and significance of water quality around the world, Krabi Province and its water usage, factors that affect water quality, and finally treatment methods that will address the water quality issues in Krabi. Together these sections will create a basis of knowledge that justifies our methods for accomplishing our research objectives in the methodology chapter.

## 2.1 Clarification of Water Quality

Our project heavily centers on analyzing and finding methods to improve water quality. In order to address problems surrounding water quality, we must establish a working definition for exactly what "quality" water means. Thailand follows the World Health Organization (WHO) established guidelines for providing water to its residents. The WHO constructs these guidelines as a reference for systems that produce high quality water. Nations can then utilize these protocols to create their own standards for water quality. As we stated previously, high quality, or clean water, is water that presents no harm when it is used for its intended purpose (Florida Keys, n.d). There is no universal or global set of water quality standards, as each country specifies its own criteria for quality based on geologic, economic, and cultural factors (World Health Organization, 2004). For examples on the criteria Thailand utilizes to determine water quality, Appendix C contains Thailand's groundwater quality standards in Table 2 and Groundwater Quality Standards for Drinking Purposes in Table 3 (Ministry of Natural Resources and Environment, 2008).

## 2.2 Overview of Villages

Our project specifically focuses on addressing problems related to distributed water in the villages of Baan Tha Lane and Baan Tha Thong Lang. These villages are located in the province of Krabi in southern Thailand and lie along the western coast adjacent to the Andaman Sea. Our sponsoring organization, the PDA, is working with these communities as a result of the 2004 tsunami in the Indian Ocean. The tsunami devastated many coastal communities including those of Thailand. The country suffered from estimated economic losses of fourteen billion baht, 4500 houses destroyed, and 8000 people dead or missing (Srivichai, 2007). As a result of the flooding caused by the tsunami, the Baan Tha Lane and Baan Tha Thong Lang communities were left without access to usable water. They did not have enough money to connect to the public water supply that feeds to larger, wealthier communities in the region. To address this problem, the PDA constructed a water supply system for the two villages. Currently, a pump draws water from a deep well in the area. The water is stored in a single tank and then distributed as needed to households through pipe networks. The communities have sufficient water at this time, but the PDA has been hearing complaints from the villagers about threats to their livelihoods that are linked to the quality of the water in the area. Our aim is to identify how to alleviate the grievances expressed by the villagers by addressing the water quality issues in these communities.

## 2.3 Krabi Province in Thailand

No community exists in a vacuum. Our two villages exist within Krabi, and as such, the province as a whole plays a large part in what constitutes the economic conditions and environmental features of these two communities. The following sections cover general information on Krabi including its major economic activities and main sources of income. Following this, we discuss different water sources in the province and their poor water quality caused by contaminants, and turn special attention to aquifers, which are the main water sources for the two villages in our project. Finally we expand upon aquifers' susceptibility to poor water quality and how this condition is a health risk for Krabi's inhabitants.

### 2.3.1 Overview of Krabi

Meaning "sword" in Thai, Krabi derives its name from a legend in which villagers find a sacred sword and present it to their governor. As seen in Figure 1, Krabi is located in the country's west coast on the Andaman Sea about 800 kilometers south of Bangkok and has a population of over 440,000 people. The economic activities in the area stem from agriculture, fishing and tourism.

Figure 1: Location of Krabi Province in Thailand (Wikipedia)

Krabi contains over 130 islands, which makes it a distinct archipelago region. Tourists can find in Krabi white sandy beaches, coral reefs, caves, and waterfalls. These attractions turn the province into a top tourist destination in Thailand's southern region (Tourism Authority of Thailand). Boats navigating to some of the most beautiful islands in the country such as Koh Lanta and Koh Phi Phi National Park leave on daily basis from Krabi's main port. Hence, activities related to tourism are large sources of income for the province.

However, the main source of income for Krabi Province remains in the agricultural sector, specifically the exportation of raw products such as rubber and oil palm. The province possesses a developed rubber industry where rubber is the main crop of the province followed by oil palm. Rubber and oil palm together account for 95 percent of the entire agricultural land in the province ("Climate Change Impacts", 2008). In addition, other aquaculture and agricultural related activities exist such as inshore fishing, coconut, coffee, and rice plantations (Chinvanno, S. 2013). The quality of water landholders use to irrigate their crops is crucial for the quality of the agricultural products. This becomes more important when most of the population makes a living from these activities.

Krabi Province possesses abundant water sources including rivers, canals, mangrove swamps, and aquifers. The two main rivers of the province are the Khlong Krabi Yai and the Khlong Krabi Noi which run from the inland mountains all the way to the coast. The fishing, agriculture, and livestock breeding businesses all are dependent on water quality from these sources for their success. However, low water quality is an increasing concern in the province.

### 2.3.2 Aquifers in Krabi

Out of all the available water sources in Thailand, the majority of Thais receive their water from underground sources. This holds true for the two villages we are addressing in our project. As previously mentioned, these communities draw their water from a deposit of underground water through a well. These underground reservoirs, commonly known as aquifers, consist of layers of porous, sedimentary rock that hold large quantities of water. Excess rain soaks through the ground and replenishes the aquifers periodically over time (Freedman, 2003). Communities can then use systems of pumps and wells to bring the water to the surface for human use. The monsoon climate of Thailand plays a key role in both the quantity and quality of the water in the aquifers in the country. In Thailand, the months from January until May are generally dry, and the months from June until December generally wet. Figure 2 below depicts the rainfall accumulation by month for Krabi Province.

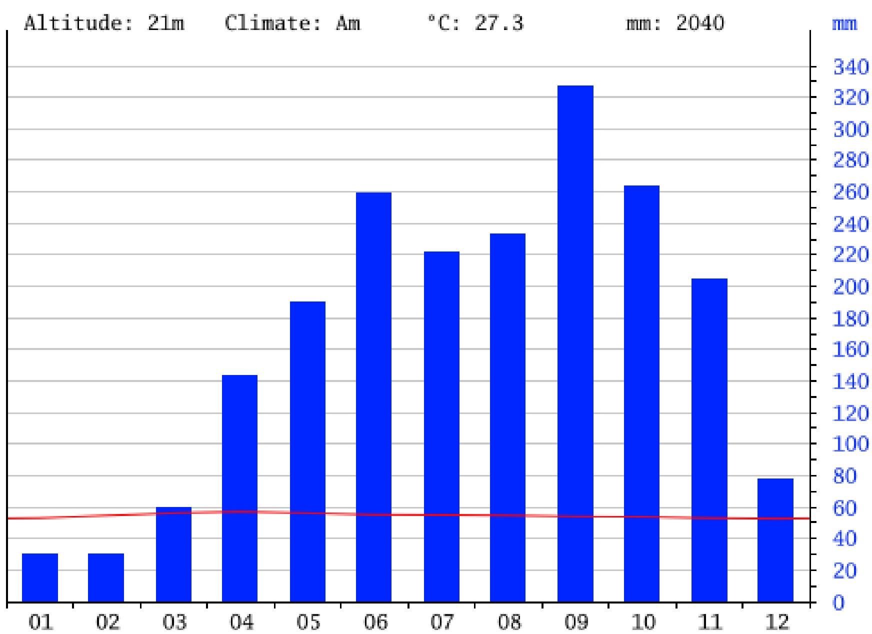



**Figure 2: Monthly rainfall for Krabi Province (climate-data.org).**

The content of aquifers is not only subject to rainfall, but also to what enters into them from the surrounding environment. The mineral compositions of the rocks lining an aquifer greatly affect the inorganic materials dissolved in the water. A buildup these materials can cause many common water quality issues such as hard water, high salinity, and manmade pollutants. High salinity is an especially common issue associated with aquifer water in Thailand. Large concentrations of salt mix into groundwater deposits as a result of excessive pumping to bring the water to the surface (Nettasana, 2012). Humans are the main cause of salinity in groundwater due to activities including salt making, deforestation, and farming. Humans are also responsible for polluting groundwater sources by way of chemical detergents and organic waste. These pollutants have the ability to seep far underground and contaminate groundwater sources. With the Thai people so dependent upon these sources of underground water, such pollutants pose a significant problem. These causes of poor aquifer water quality greatly affect the utilization of water throughout the region.

## 2.4 Water Usage in Krabi, Thailand

The following subsections describe some of the main usages of water in Krabi. Specifically, each subsection identifies water usages in agriculture, aquaculture, and more domestic purposes. All three of these areas are especially pertinent to the villages our team will be addressing. Access to quality and reliable water is a highly important criteria for the communities in this area.

### 2.4.1 Agriculture

The villagers of Baan Tha Lane and Baan Tha Thong Lang are mostly farmers, meaning that their lifestyles relate to the types of crops that they grow. Krabi's main crops are rubber and oil palm. Rubber accounts for almost 50 percent of the entire agricultural land of the province and oil palm accounts for almost 46 percent. These two crops represent an average annual production value of around 630 million USD, being the main income for the province along with tourism ("Climate Change Impacts", 2008). Figure 3 depicts the geographical location of agricultural land use in Krabi, with oil palm and rubber dominating the usable land area (Chinvanno, S. 2013). Given the vast majority of the agricultural sector that rubber and oil palm occupy, it is likely that the villagers in our areas of interest will be dependent on one or both of these cash crops.

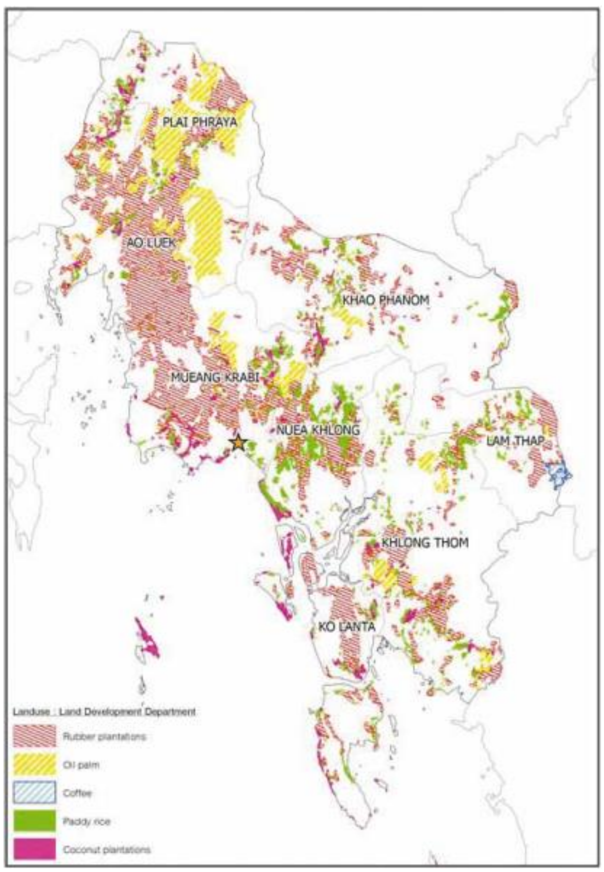



**Figure 3: Agricultural land use in Krabi Province**

As stated above, proper irrigation helps to improve the quality of most crops (Gheewala, Shaabir H., 2014). As such, crops may demand high volumes of water in order to flourish, which may have to come from sources other than rainfall. Figure 4 shows that the southern region of the country demands 10% of the total water for crops irrigated in Thailand and that oil palm alone demands 9% of crop water. As a result, any characteristics of the water from the aquifer have the potential to affect the crops of these villages, and thus, the livelihoods of the farmers.

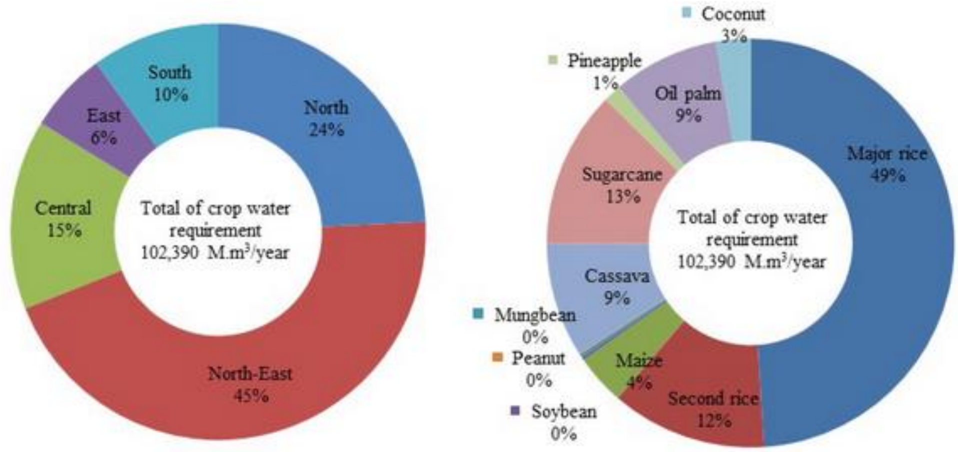



**Figure 4: Total water requirements for crops cultivation classified by regions in Thailand and Total water requirements for crops cultivation classified by products in Thailand (Water, 2014)**

### 2.4.2 Aquaculture

Although fishing is not the main source of income or occupation in Krabi as a whole, it is the predominant one for most coastal communities in the province. Fisheries operate in small boats near the shore and entirely rely on family members to perform the work (Chinvanno, S. 2013). The Provincial Fishery Office identified more than 4900 fishery households throughout the province whose products mainly serve local consumption and seafood tourism demand. Moreover, there are about 800 shrimp farms in Krabi that operate almost 2,500 ponds ("Climate Change Impacts", 2008). The properties of the water of shrimp ponds including the salinity and solid levels, as well as the types of nutrients dissolved in water are important in determining the quality of the product. Years ago, aquaculture in the region was at risk due to the poor conditions of the fishing ponds (Dierberg, Forrest, 1996). These recent improvements serve as a reminder that high quality water is essential to the development of sustainable and profitable aquaculture activities that coastal communities in Krabi rely upon.

### 2.4.3 Domestic Use

The Krabi citizens depend on surface and underground water to perform their daily activities such as cooking, cleaning, personal hygiene and many others that require water in some form. The quality of water has been acceptable for domestic use in the province. However, the expansion of some economic sectors could threaten the water quality in the future as a result of pollution from industrialization ("Climate Change Impacts", 2008). The two villages our project focuses on lack any sort of treatment method for their water supply. This absence of treatment exposes the communities to any form of pollutant or pathogen that may be present in the aquifer water, which can lead to diseases and other health risks (Population and Community Development Association Information, 2014). Therefore, having access to quality water is vital for these villages to be able to function and be healthy.

## 2.5 Factors Affecting Water Quality

The poor quality of water in Baan Tha Lane and Baan Tha Thong Lang characterizes for having both hard water and water high in levels of alkalinity and salinity. However, microbiological contaminants can also affect water quality such as viruses, bacteria, and other microorganisms that are not only from geological causes. These factors could become potential threats for the quality of crops as well as for the villagers' health.

### 2.5.1 Hard Water

The depletion of water sources due to hard water is a major concern in southern Thailand where the villages of Krabi are located. The effects of hard water diminish the water's quality and provide concerns for sanitation and drinking. Depending on various levels of water hardness; soft, medium, or hard, drinking water is usually not a major concern. In levels of soft and medium water, taste is the biggest factor concerning water hardness. Hard water does contain minerals such as magnesium and calcium, which experts advise to take daily (Kocak, 2011). However, when the water hardness is "hard", large amounts of consumption may lead to cardiovascular disease, anencephaly, and cancer (World Health Organization 1996). Nevertheless, most of Thailand is now consuming bottled water (Kruawal, 2005).

Scientists define water hardness as a qualitative measure of the composition of several mineral ions, most commonly containing calcium and magnesium. Several factors influence the hardness of water and the properties that constitute poor water quality. Mineral ions that characterize hard water easily affect underground sources of water because of the sedimentary rocks that line an aquifer. Often sedimentary rocks, such as limestone, line the aquifer level of underground systems which present high levels of polyvalent ions (World Health Organization, 1996). In addition to sedimentary rocks, human industrialization is the cause of increase of water hardness. As Thailand is a developing nation, their methods of water waste disposal are often not as regulated as other nations in Europe and North America. This often un-biodegradable waste seeps into the ground and negatively affects the water quality being produced by aquifers.

### 2.5.2 Alkalinity

Water that is high in alkalinity exhibits traits that may be harmful to a water network environment. This is important as we know that these villages currently face damages in their pipes, pumps, and home appliances. Similarly, high alkalinity is detrimental to agricultural and domestic needs. The proper definition of alkalinity, given by the Oxford Dictionary of Environment and Conservation, is 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" can be more accurately described as the capability of water to sustain a healthy pH level, not becoming too acidic or basic. When we consider water to be high in alkalinity, its usefulness becomes diminished and it will exhibit harmful qualities.

The impact of the coastal water plays a significant part in understanding the composition of minerals that cause the current water to contain high amounts of alkalinity. As with the characteristics of hard water, ion exchange affects water high in alkalinity. Through the results and discussions of Oak-Bae Kim and Hee-Youl Park's analysis of seawater intrusion, they determined that the hydrate, sulfate, and calcium ions found in fresh groundwater sources contain the same charge as sodium and chloride ions that are found in seawater (Kim 1998). This study suggests that seawater intrusion can contribute to producing water characterized as high in alkalinity.

### 2.5.3 Salinity

Many of the factors that affect the alkalinity of water also contribute to the salinity of water. The salinity level found in groundwater has direct effects to the uses of the water both domestically and agriculturally. Water which contains high amounts of salt is not suitable for agricultural use because too much salt limits the ability for the roots to absorb water, preventing the plants from acquiring the necessary nutrients (Singh, 2011). We can calculate the amount of salt content in water and determine whether it is suitable for agricultural means or not. Domestically, water used for human consumption can contain higher amounts of salt, however high amounts of salt and nitrate, a compound salt, can result in health complications if consumed. Additionally, water high in salt content has corrosive properties that can result in damage to pipes.

Characterizing water salinity, or saline water, such as seawater, comes from the characteristics of the ions that "derive from weathering and erosion of rocks on the continents, as well as material derived from natural forest fires, volcanic eruptions, and air pollution" (Oxford University Press, 2007). Salinity affects groundwater through the layers of soil that surround the aquifers as well as the layers which are between the water possessing rocks and the surface.

Surface water such as polluted lakes and rivers in addition to coastal water can affect the aquifers which produce groundwater. These sources of water are absorbed at different rates based on soil composition, affecting the amount of mineral ions that can influence the quality of water. We can determine the amount of water in the soil based upon the characteristics of its two aqueous layers. The first layer is the surface, where water is free to flow, much like how little streams flow through the grass when there is heavy rain. The second layer is the water molecules that absorb water. This second layer, depending on the surface water forces, can hold large amounts of water creating an ionic charge (Singh, 2011). The amount of water that the soil can retain is proportional to the salinity level of the water. The less water absorbed by the soil, the higher the level of salt ions (Singh, 2011). This process helps to illustrate how surface water, such as seawater, can influence the salinity level in the soil impacting the ion-exchange that occurs between the water molecules in the aquifers and water molecules in the soil.

### 2.5.4 Biological Contaminants

Biological contaminants are living organisms that can be harmful for animal or human health when absorbed into the body (Business Dictionary, n.d.). We can find these dangerous microorganisms in untreated water and relate to potential health diseases in the population consuming the water. Cholera, acute diarrhea, dysentery and food poisoning are common diseases in Krabi (Suthienkul, 1992). The microorganisms responsible for these diseases are various types of viruses, bacteria and fungi. We can find them naturally in water but human pollution cause others. Table 4 in Appendix C shows the most common microorganisms found in water. Communities can easily eliminate these microorganisms through simple methods of water disinfection. The villages in Krabi are not treating the water used for consumption purposes, becoming a potential threat for villagers. Eradicating the biological contaminants from the water is vital for the health of the communities.

## 2.6 Feasible Treatment Methods

This section introduces different methods for treating water. Water alkalinity, salinity, hardness, and waterborne pathogens all pose risks to the residents Baan Tha Lane and Baan Tha Thong Lang due to the fact that they lack any sort of treatment process for the water they extract from their well. Accordingly, each of the processes in this section aims to regulate one or more of the afore-mentioned water properties. Each subsection defines a single water treatment method, describes how the method works, and identifies the pros and cons of the method. The end of the section serves to recap each method with respect to the others and make general comparisons.

### 2.6.1 Slow Sand Filtration

Slow sand filtration is a method primarily aimed at eliminating harmful microbes from a water source. Given the prevalence of waterborne disease, mitigating the amount of pathogenic contaminants found in water is of great importance, especially in developing nations where water treatment is often lacking. The two villages we will be addressing are located in a rural area of the Krabi province and do not have a treatment system for their water.

Slow sand filters function by passing water through layers of sand and gravel to filter out pathogens and particulates that can be harmful when consumed. They are typically one to two meters in depth. Very fine sand composes the upper portion of the filter, which is supported by layers of more course gravel underneath. The very top layer of sand is responsible for most of the filtration in this method. Charged sand particles capture organic particulates and microbes such as bacteria. As the sand captures these microbes, a biological community forms below the top few centimeters of sand. This ecological layer, known as schmutzdecke captures and eliminates pathogens from the water that pass into it. After a few months, the schmutzdecke becomes so populated that water cannot pass through it. At this point, a person must scrape off the top layer through the schmutzdecke. When the sand is sufficiently depleted, a person must add sand to the filter (Haider, 2006).

Based upon the research of Husnain Haider (2006), slow sand filtration is "the most cost effective method of disinfecting rural water supplies in developing countries." The foremost reason for this is that slow sand filtration can operate without power, and does not require any chemicals or replaceable parts, such as individual filter media. As an added advantage, training individuals on how to operate a slow sand filter is easy, and the process requires little maintenance. A final characteristic that makes these filters especially applicable for rural areas is that a person can assemble them with almost no specialized parts. Those seeking to constrict these filters can typically find necessary components within a local area, especially if a riverbank or other source of sand is nearby. This negates having to transport large amounts of equipment if the filter will be used in an isolated area ("Slow Sand," 2000).

Slow sand filtration does have disadvantages. This method of disinfection has no residual effect, so after water leaves the filtration process, it is susceptible to contamination again until it reaches its final destination. For this reason, the water may be treated chemically, such as with chlorine, to provide residual disinfection. An alternative is to boil the water at the point of use, but this adds greater cost to the treatment process through the use of fuel for boiling (Haider, 2006). As the name implies, slow sand filtration also processes water at a slow rate, and substantial space may be needed for the system depending on the size of the population it serves. Municipal water systems require extensive land area for such filtration processes ("Technologies for Upgrading," 1989). Finally, and as mentioned previously, slow sand filters can be easily clogged by high numbers of dissolved particles. This is a problem for areas where excessive rainfall may turbid the water sources, such as Thailand during the rainy season. As an example, many slow sand filtration plants in Pakistan perform poorly during the rainy season as a result of increased turbidity in the water (Haider, 2006).

### 2.6.2 Ultraviolet Disinfection

Ultraviolet disinfection, or UV disinfection, serves a similar purpose to slow sand filtration in that it provides an efficient method of removing pathogens from water that can cause illness. The process works by bombarding any microbes present in the water with ultraviolet radiation. The UV radiation breaks down the nucleic acids within these microbes, either killing them, or rendering their ability to reproduce inoperable, thus removing them as a threat to human health. For this process, a person fills a tank houses a UV bulb with water. As water enters one end of the tank and exits the other, the bulb doses the water with radiation. Different types of microbes require different amounts of exposure to radiation before they are rendered inert, though twelve seconds of exposure is often sufficient to produce water of drinkable quality (Gardgil, 1997).

UV disinfection is applicable to rural communities, due to it having a low operating cost and needing little maintenance. Once established, little else is needed besides the electricity to run the process. Bulbs must be cleaned periodically to ensure enough radiation is cast into the water. Unlike slow sand filtration, UV radiation can process relatively large volumes of water at a fair pace. UV disinfection exists in forms for large scale filtration, but also in smaller forms (Gardgil, 1997). Such smaller processes can treat 4 gallons of water every minute and serve a community of hundreds (Haider, 2006). Initiatives such as the UV Tube Project specifically aim to use small scale

UV disinfection like this to improve water quality in rural and impoverished areas ("UV-Tube," 2003).

In a similar vein to slow sand filtration, UV disinfection has no residual effect, though there is an even more detrimental stipulation. While UV radiation damages the nucleic acids in pathogens, visible light can actually repair this damage, meaning sterile viruses or bacteria can regain the ability to reproduce and become dangerous. It is for this reason that treated water must not come into contact with visible light for significant periods before consumption, including in transport (Qiu, 2004). As another parallel to slow sand filtration, turbidity will decrease the effectiveness of UV disinfection. Suspended particles will block light from the UV bulb, preventing some pathogens from receiving exposure (Gardgil, 1997). For this reason, water should be pre-filtered to reduce turbidity before undergoing UV disinfection.

### 2.6.3 Chlorine Disinfection

A third viable method for removing unwanted microbes from water is disinfection through chlorine. Chlorine functions similarly to UV disinfection in that it sterilizes or kills pathogens present in the water. Chlorine operates as an oxidizing agent and incapacities microbes by oxidizing their organic molecules (Calderon, 2000). One can transport chlorine in the form of a white powder known as calcium hypochlorite, which is prevalently used to disinfect the water supplies of rural and small communities (Haider, 2006). Once the powder makes contact with the water, chlorine releases into the water stream.

Chlorine is a highly effective disinfectant for a wide host of pathogens, and its usage is common place in the treatment of water supplies and swimming pools. Once chlorine enters into a water supply, it will continue to disinfect the water for a time as it is transported to its ultimate point of use. Because of this residual disinfection, chlorine is often added to the outflow of water treatment processes that do not provide such residual effects (Haider, 2006).

The effectiveness of disinfection using this method is dependent on the qualities of the intake water. For chlorine disinfection to operate properly, the water must be below a pH of 7.0 so that the chlorine remains in a state that can disrupt organic molecules. This may be problematic for our project, as the PDA reports that the well water we aim to treat is high in alkalinity. This indicates water of a pH significantly higher than 7.0 (Barnes, 1981). Turbidity also plays a role in chlorine based disinfection. Viruses or bacteria may be shielded within suspended particles present in water, which allows them to remain protected from chlorine in the surrounding liquid. Chlorine disinfection has an added detriment in that chlorine can react with organic compounds to create disinfection byproducts, many of which pose severe health hazards such as cancer when consumed in sufficient quantities ("Bromoform," 2011). Fortunately, the World Health Organization deems the negative effects of consuming untreated water to greatly outweigh the risks posed by disinfection byproducts (WHO, 2006). Even so, chlorine disinfection can greatly benefit from the implementation of pre-filtration to reduce the amount of suspended particles and organic matter present in the actual treatment process.

### 2.6.4 Lime Softening

As hard water can have detrimental effects on the infrastructure through which it passes, reducing the hardness of this water may relieve the pressure of having to maintain pipes and pumps from these villages. Water can have its hardness diminished, or be "softened," through processes that mitigate the presence of ions that cause hardness, such as magnesium and calcium. Lime softening is one such process that can remove these ions from water.

Lime softening is a multistage process in which quick lime, or calcium oxide, reacts with dissolved ions in water to form a removable substrate, eliminating hardness from the water. Initially, water must be aerated if it has a high concentration of carbon dioxide. Ground watery typically has such high concentrations, and as the water source our group aims to treat is a groundwater well, aeration will most likely need to be present in our lime softening process. After aeration, an operator adds quick lime to the water. With lime present, A pH of 10.3 is suitable for calcium to precipitate out of the water and form a substrate, and a pH of around 11.2 is required for the precipitation of magnesium. While most natural waters have a pH of below 8.0, the pH of water can be raised by adding more lime (Barnes, 1981)("Lime Softening," 2010). The solid substrate formed by the chemical reactions with lime then collects at the bottom of a basin as the water passes through it. This substrate is subsequently removed. Finally, an operator lowers the pH of the water again through the addition of an acid such as hydrochloric acid and stabilizes the water through recarbonation ("Lime Softening," 2010).

The lime softening process has a number of advantages in the diversity of particles it can regulate. Not only does it remove hardness ions, but certain organic compounds, heavy metals, certain isotopes of radium, and even suspended particles that cause turbidity. An additional benefit is that lime softening requires little pretreatment, if any at all ("Lime Softening," 2010).

The drawbacks of this method are also pronounced, especially for developing areas such as our project site. As outlined above, lime softening requires a number of chemicals which may be difficult for those in rural, isolated, or impoverished areas to acquire. Lime softening also utilizes a fair amount of mechanical processes and requires involved maintenance and monitoring. Establishing and up-keeping this process would be a great challenge without specialist help. Furthermore, handling the chemicals used in the process may pose a health risk. Lastly, one must dispose of the sludge composed of the substrate from lime addition. This poses a unique environmental challenge, as simply dumping runoff into the surrounding environment is not environmentally responsible ("Lime Softening," 2010).

### 2.6.5 Ion Exchange

The groundwater source our team aims to address is high in hardness, alkalinity, and salinity, among other potential items of interest. In various forms, ion exchange treatment has the capacity to regulate each of these three characteristics. Ion exchange operates by passing water past 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 will be substituted for the ions within the resin, thus removing the unwanted ions. As an example, calcium and magnesium can be substituted for sodium or potassium ions ("Filtration Facts", 2005). Eventually, the substitution ions within the resin will become depleted, and must be regenerated with new substitution ions. To perform regeneration, the ion exchange device is "backwashed" by pumping water saturated with substitution ions past the resin in the opposite direction of normal flow. This process also removes any fine particles that have become trapped in the resin ("Ion Exchange," 2009).

The most common use of ion exchange is to remove sodium from liquids. One can use hydrogen in this process as a substitution ion. In this case, the pH of the treated water decreases as the hydrogen concentration increases ("Ion Fact Sheet," n.d.). This is especially applicable for our endeavors, as the water will have a high pH due to high alkalinity and have a high concentration of sodium. For this reason we may be able to mitigate two of the problems with the water quality using a single process. If the pH of the water becomes too low, the addition of calcium carbonate can raise it ("Ion Fact Sheet," n.d.). As stated before, ion exchange can also reduce the hardness of water, thus remedying a third issue with our water supply. However, different resins are needed to remove harness than those that remove salinity, meaning that a separate ion exchange process is needed for softening. Ion exchange also has an advantage in that, unlike lime, the treatment process has few steps and requires a limited amount of machinery.

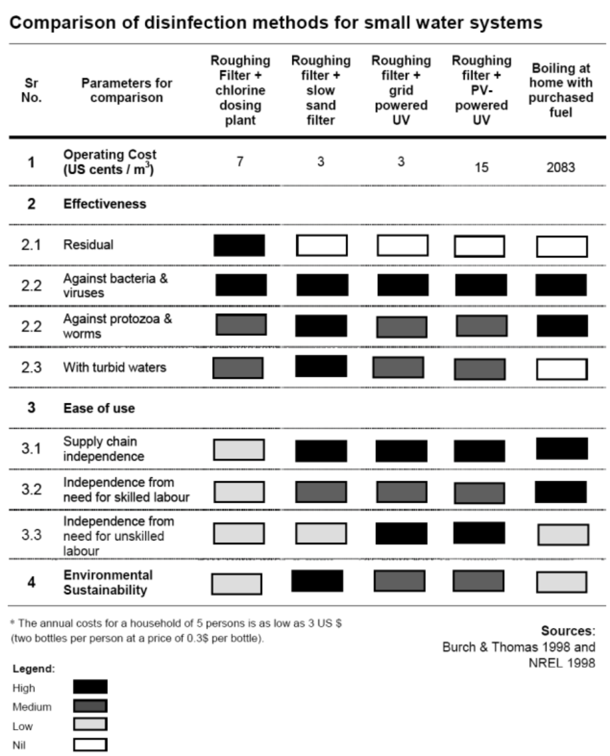
Akin to lime softening, using ion exchange requires the acquisition of specialized chemicals. This may pose a difficulty to those in isolated areas. However, the quantity of resin depends on the size of the community being served. Also like lime softening, the creation of brine results from the ion exchange process, specifically from backwashing the system. This waste water demands some form of recycling or disposal. The dumping of such brine poses environmental problems ("Ion Exchange," 2009). For the water softening, sodium is often used to substitute the undesired ions in the water. Given that the water we wish to treat is undesirably saline, we will not wish to add further sodium to the water supply. This can be avoided by using potassium in place of sodium.

### 2.6.6 Comparison of Treatment Methods

Each of the treatment methods listed above contains its own sets of advantages and disadvantages, though it is difficult to directly compare all methods due to the fact that different treatment processes serve different purposes. This section provides a general comparison of the treatment processes covered thus far.

Slow sand filtration, UV disinfection, and chlorine treatment all serve to disinfect volumes of water, so they are the most easily comparable. Table 1 below compares these treatment processes with regards to a number of parameters that may be applicable to our project. This table is a truncated form of one provided by Haider (2006). Distillation is included on the chart as a baseline for comparison, as it is one of the oldest and most reliable ways of reducing water to a pure state free of any undesired particles, though it is highly inefficient, as evidenced by its cost on Table 1 ("Saline Water," 2014). Additional processes covered on the table are chlorine treatment, slow sand filtration, and UV disinfection using power from a power grid, and using power from photovoltaic cells. Something particularly noteworthy is that while chlorine generally performs worse than the other treatment processes in terms of ease of use, it is the only one with any residual effects, which makes it an especially desirable treatment method if water is not going to be disinfected at its point of use, such as boiling it.

**Table 1: Comparison of disinfection methods for small water systems (Haider, 2006)**



**Comparison of disinfection methods for small water systems**

| Sr No. | Parameters for comparison | Roughing Filter + chlorine dosing plant | Roughing filter + slow sand filter | Roughing filter + grid powered UV | Roughing filter + PV-powered UV | Boiling at home with purchased fuel |
|---|---|---|---|---|---|---|
| 1 | **Operating Cost (US cents / m$^3$)** | 7 | 3 | 3 | 15 | 2083 |
| 2 | **Effectiveness** | | | | | |
| 2.1 | Residual | High | Nil | Nil | Nil | Nil |
| 2.2 | Against bacteria & viruses | High | High | High | High | High |
| 2.2 | Against protozoa & worms | Medium | High | Medium | Medium | High |
| 2.3 | With turbid waters | Medium | High | Medium | Medium | Nil |
| 3 | **Ease of use** | | | | | |
| 3.1 | Supply chain independence | Low | High | High | High | High |
| 3.2 | Independence from need for skilled labour | Low | Medium | Medium | Medium | High |
| 3.3 | Independence from need for unskilled labour | Low | Low | High | High | Low |
| 4 | **Environmental Sustainability** | Low | High | Medium | Medium | Low |

* The annual costs for a household of 5 persons is as low as 3 US $ (two bottles per person at a price of 0.3$ per bottle).

**Sources:** Burch & Thomas 1998 and NREL 1998

**Legend:**
High
Medium
Low
Nil

The remaining two processes posed in this chapter are a bit more difficult to compare because of the different functions that each can serve. There is however, some overlap in their applications. Lime softening is used to soften hard water and also raises pH. It has disadvantages in that it is a multistep process with a fair amount of machinery. Additionally, the pH control is a separate process which must be done in order to perform lime softening, and is not an actual part of the lime softening itself, meaning that the pH control used could be applied to any method. Ion exchange can be used to treat hard water, saline water, and a number of other water properties, though the treatment of each property may require a separate treatment step. Ion exchange overall is a simpler process than lime softening and also may raise pH, depending on what other characteristics the water is being treated for.

## 2.7 Background Summary

This background chapter serves to inform the reader of useful material they should be familiar with to comprehend the rest of the report. As stated before, the communities of Baan Tha Lane and Baan Tha Thong Lang in Krabi province are currently using a makeshift water network system constructed by the PDA after the tsunami in 2004. This system supplies poor quality water to the people of these villages from an aquifer located deep beneath the ground through a network of pipes. The WHO and Thai authorities have recommended guidelines for safe drinking water, but no international standards exist.

Krabi Province has an economy that relies heavily upon water quality. The agriculture and aquaculture sectors such as the rubber, oil palm, coconut, coffee, and fishing industries all need sufficient quantity and quality of water to thrive. The monsoon climate of Thailand divides the year into rainy and dry seasons. The water from the rainy seasons irrigate the crops for these industries and replenishes the aquifers that the people of Krabi use for their water needs. Unfortunately, a variety of factors affect the water are located in the aquifers. Some of these factors such as hard water, alkalinity, and salinity are caused by minerals surrounding the aquifers leaching into the water. Manmade pollutants and biological contaminants are commonly present in underground water sources as well.

There are various water treatment methods currently in existence that are low enough in cost and to be implemented by the communities. These methods are all low tech and are considered feasible options. Examples of these treatment methods include slow sand filtration, ultraviolet disinfection, chlorine disinfection, lime softening, and ion exchange. After completing our research objectives in the methods chapter, we will refer back to these potential treatment solutions to choose the most viable option.

# 3. METHODOLOGY

Our goal for this project is to aid the villages of Baan Tha Lane and Baan Tha Thong Lang in Krabi to address the socially important problem of dealing with damaged pipes, pumps, and appliances due to poor water quality in the region. To achieve this goal, the four objectives we will accomplish are to characterize the current water supply system that creates challenges for the communities, to understand the villagers' usage and perception of the current water distribution network, to analyze the current water quality delivered by this system, and finally to develop a set of recommendations for the Population and Community Development Association (PDA) to improve the distribution network. We will complete these objectives over an eight week period working from Chulalongkorn University in Bangkok, Thailand.

In this chapter we will outline our approach to accomplishing our four objectives. To begin, we will take an assessment trip to characterize the current state of the water system. This trip will allow us to gather information about the network's composition, damage, needed maintenance, and location from the villages. We will also need to gain knowledge on how the people of these villages use their water and perceive the PDA-built system. Our team will accomplish this through the use of interviews conducted with various members of the communities. With the help of our Thai partners, we will also be performing water quality testing. This will allow us to determine the composition of the water and potential contaminants that may be adversely affecting the community members and infrastructure of the system. Finally, we will use the results from the observations, interviews, and water testing to develop recommendations to the PDA on how to improve the water system in the two villages.

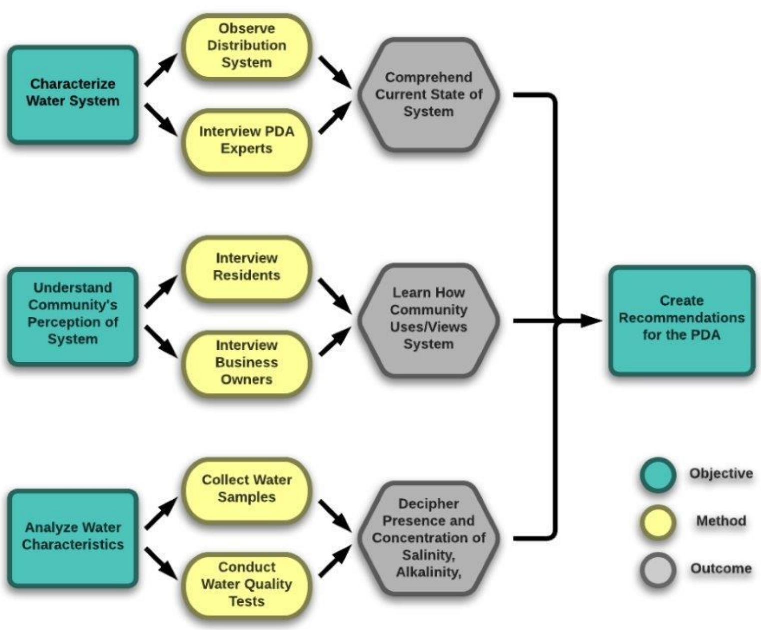



Figure 5: Methodology Diagram

## 3.1 Characterize the Current Water System

Our first objective is to characterize the water distribution system that the PDA built after the tsunami. This step is vital because we need to observe the system in person and understand how it works before we can continue with the next steps. We will accomplish this objective by completing two tasks during an assessment trip to the villages at the start of the project. The first task is to observe the water distribution system. This includes determining the location of the well and tanks as well as noting any corrosion and leaks to pipes and pumps, maintenance on the system, and the volume of water in the tanks. We are collecting this information because we need to comprehend the extent of the damages to the current water system.

Our second task on the assessment trip is to conduct standardized interviews with members of the PDA responsible for the construction and maintenance of the system, as well as with experts in the communities who are knowledgeable about the system. Our team will conduct these interviews at the PDA office located in the city of Krabi as well as on site at the villages, with the help of our Thai partners. In order to determine who we will want to interview, we will contact the PDA prior to this trip to determine which employees and village residents are most knowledgeable about the water system. The interviews will be recorded with consent from all parties so that our team may analyze them at a later date. Our aim for these interviews is to gain information on aspects of the distribution system that our team cannot obtain through observation. In his book *A Practical Guide to Policy Analysis* (2000), Eugene Bardach explains that the practice of consulting experts not only adds credibility to work, but also gives the project political backing from the people most likely to be critical of the work. Some examples of interview topics include: learning how the system works, whether or not the water is being treated, current maintenance, and their opinions on how to address the system downfalls. The complete list of interview question is in Appendix B.

After accomplishing these two tasks, our team will have detailed notes outlining our observations on the system as well as the interview answers from the experts. We will use the notes of observations as a reference throughout the project. By knowing the specific defects of the system, our team will be able to focus our attention on the most crucial issues to address. For example, if we find that the pipes are rusted and leaking but the pump and tanks are functioning adequately, we will know that our focus must be on the pipes. We will use this knowledge of the specific defects of the system to develop a method for analyzing our interviews with the experts to highlight the discussions which pertain to all of the issues, even if we are unable to address them later on. This will help us better categorize the responses for use later on in our analysis. To accomplish this, we will first use our notes and recordings of the interviews to create a transcript of every interviewee's answers. Then we will utilize a color-coded system where similar answers on a specific topic, from all interviewees, will be highlighted in the same color. At the end, we will address any outlier questions and/or responses that did not receive a color by determining there relevance to the defects of the water system and contacting the interviewee again for clarification, if possible. Based upon these categories, our team will come to a consensus on the top priorities we will need to address from the opinion of multiple experts. These opinions as well as our observational notes from the assessment trip will give us a substantial base of knowledge on the priorities we must focus on for the remainder of the project.

## 3.2 Understand the Community's Perception of the System

Our second objective is to recognize how the residents of Baan Tha Lane and Baan Tha Thong Lang use and perceive the water distribution system. This step is necessary because we must identify any damage to infrastructure and health issues the consumers of the water system face to tailor our project to their needs. We will gather this information from the community through the use of standardized interviews. These interviews are superior to lightly structured interviews, in this case, because they tend to not acquire an excessive amount of irrelevant data (Knight, 2008). This will help us better analyze our interview responses by eliminating irrelevant data. These interviews will give us knowledge on how people use their water and what opinions they have on the way they currently receive water.

Our team will develop a comprehensive list of interview questions based on information that we are missing from the villagers in Krabi and our analysis of the interviews we conducted with the experts. The current interview with questions created from important information we are currently missing from the people of the Krabi communities is in Appendix A. These questions employ a mixture of introducing questions followed by probing questions when necessary. There will also be demographic questions we will ask each interviewee in order to gain a better knowledge of our data later on. Examples of topics we will be covering include learning how the water is used, where the water they use comes from based upon specific activities, if the quantity of water supplied is sufficient, and specific complaints consumers have with the system. We will conduct these interviews with the help of our Thai partners to reach a large number of residents who use the water system.

Our next step is to identify the population and sample size. The population in this scenario is the entirety of the people that live and work in the two communities that utilize the PDA's water system. We cannot determine a sample size at this point because we do not know the population of the communities. However, we do know that our sampling frame will utilize a stratified sampling method of two categories consisting of people who use water for residential purposes as well as for business purposes. We will randomly select people from each category by asking for volunteers in a common gathering place such as a market, and by approaching local businesses that rely on water from the system, such as fisheries and processing plants for oil palm and rubber. We will ask for consent from all interviewees before we record them and ensure anonymity.

Once we complete all the interviews we feel is necessary, based upon our sample size, we will work with our Thai partners to translate the responses into English transcripts. We will use the same color coding method as before with these new interviews to classify the responses into well-defined categories based upon different water usages, physical infrastructural damages, complaints with the system, and how these issues coincide with the defects of the water system. Once we organize the interviews, we will use the categorized responses to make a list of general similarities between responses. For example, we will compile a list of all uses the community members have for the water supplied from the aquifer. We will also create a running list of appliances that the interviewees describe as damaged or destroyed by the water quality. These lists will give us a reliable data set of the most critical problems the people in the communities are facing as well as any complaints they currently have about the system. We will refer to this data when we create our recommendations for the PDA.

## 3.3 Analyze Water Characteristics

Our third objective is to analyze the composition of the water currently delivered by the system. The PDA is under the impression that the aquifer exhibits characteristics of hard water and is high in salinity and alkalinity levels. Despite this information, we will need to confirm that the presence of these contributors to poor water quality is valid. We will also detect what other solutes contribute to the unclean water and their concentration. Our team will accomplish this objective with water quality tests that we conduct on our first assessment trip.

With the help of our Thai partners, we will purchase a water quality field testing kit that is easy for people with minimal equipment and expertise to use. We will have the laboratories at Chulalongkorn University at our disposal for analysis, when we return from our trip to perform additional testing as well. An example of a field test commonly used by researchers around the world to aid in analyzing the composition of water are water quality indicator (WQI) tests. These tests are designed to help field personnel recognize agricultural nonpoint source problems and their potential causes (Terell 1989). We will choose WQI tests that specifically measure for the harmful solutes we discussed in the background chapter including; alkalinity, salinity, hardness, pH, heavy metals, and pathogen content. Examples of these tests include pH meters, Colilert Presence/Absence tests for E. Coli, etc. To better determine which of these field tests our team should utilize, we will include questions in our standardized interviews to the PDA and other water experts. If necessary, our team will repeat each test multiple times to ensure accuracy. We will redo every set of tests during the second trip to the communities to confirm our previous results. All of these testing methods require samples of water that we will retrieve from the system. We will take these water quality samples from a variety of sources including the well (if possible), tanks, faucets, and shower heads. The purpose of taking samples from these different sources throughout the system is to ensure and determine consistency of the results. We will obtain these samples with permission from all home and business owners who volunteer their space. If any samples need to be incubated, we will store them in the refrigerator of our temporary residency and transport any samples back to the lab at Chulalongkorn University that need additional testing. When we arrive in Bangkok after our first assessment trip, we will carefully process the tests and record our results.

Once we complete the water quality testing, we will have data on what elements are present in the water and their concentrations. We will compile this data into a table that clearly depicts each metal, pathogen and contaminant level in the water and compare the results to the Groundwater Quality Standards Tables in Appendix C. We will cross examine each contaminant with its corresponding concentration in the table to find where it exceeds the allowable levels. This knowledge will allow us to focus our project on recommendations that pertain to the specific contaminants that exist at dangerously high levels. Our team will research if these contaminants are responsible for the damage to appliances described in our interviews with the community residents.

## 3.4 Create Recommendations for the PDA

Our fourth and final objective is to develop a set of recommendations for the PDA regarding the water distribution system. This set of recommendations will be in the form of a presentation and a written report given to members of the PDA who are directly involved with the water system in Baan Tha Lane and Baan Tha Thong Lang. These recommendations will culminate all the data and information we accrued from our observations of the water system, interviews with the PDA employees and residents of the communities, and water quality testing results.

We will create a set of criteria for these recommendations based upon the analysis of our data from the first three objectives. Our team will base these criteria on multiple factors including cost, feasibility, sustainability, and ability to address the water quality concerns. With these criteria, we will develop a ranking system that correlates low, medium, or high values to each factor. We will use these criteria to recommend feasible water treatment methods for the communities from the examples of treatment methods we describe in the background chapter. Each of these potential treatment methods will be given rankings based upon how effectively it completes each metric (cost, long term sustainability, etc.). From this method of organizing our analysis, we will be able to decipher which treatment methods have higher rankings than others based upon its low, medium, and high designated values for the criteria.

In addition to this ranking system, we will also take into account suggestions that PDA experts provide us, including their allowable budget. We will also research similar projects that have been successfully implemented around the world for guidance (Bardach, 2000). We will present our findings to appropriate members of the PDA in the form of a professional presentation and discussion panel.


**Figure 6 Project Timeline**

## BIBLIOGRAPHY


Al-Hayeka, I., & Badran, O. O. (2004). The effect of using different designs of solar stills on water distillation. *Desalination, 169*(2), 121-127.

Arslan, H., & Demir, Y. (2013). Impacts of seawater intrusion on soil salinity and alkalinity in bafra plain, turkey. *Environmental Monitoring and Assessment, 185*(2), 1027-1040.

Bardach, E., & eBooks on EBSCOhost. (2000). *A practical guide for policy analysis: The eightfold path to more effective problem solving*. Washington: CQ Press

Barnes, D., Bliss, P. J., Gould, B. W. & Vallentine, H. R. (1981). *Water and Wastewater Engineering Systems*. Pitman Book Limited, London, UK.

Biological contaminants. BusinessDictionary.com. Retrieved December 10, 2014, from BusinessDictionary.com website: http://www.businessdictionary.com/definition/biological-contaminants.html

Calderon, R. L. (2000). The epidemiology of chemical contaminants of drinking water. *Food and Chemical Toxicology, 38*(1 Suppl), S13-S20.

Cath, T., Hai, F. I., Hildinger, F., Nghiem, L. D. (2011). Treatment of saline aqueous solutions using direct contact membrane distillation. *Desalination and Water Treatment, 32*(1), 234-241.

Chinvanno, S. 2013, A holistic approach to climate change vulnerability and adaptation assessment: Pilot study in Thailand, Adaptation Knowledge Platform, Partner Report Series No. 4. Stockholm Environment Institute, Bangkok. Available online at www.asiapacificadapt.net or www.weADAPT.org

Climate Change impacts in Krabi Province, Thailand. A study of environmental, social, and economic challenges. (2008). Retrieved December 10, 2014, from http://startcc.iwlearn.org/doc/Doc_eng_11.pdf

Dierberg, F., & Kiattisimkul, W. (1996). Issues, impacts, and implications of shrimp aquaculture in Thailand. Environmental Management, 649-666.

Diersing, N. (2009). Water Quality: Frequently Asked Questions. Retrieved 11/19/2014, 2014, from http://floridakeys.noaa.gov/scisummaries/wqfaq.pdf

Drinking Water Contaminants. (2009, January 1). Retrieved December 10, 2014, from http://water.epa.gov/drink/contaminants/

eBooks on EBSCOhost, Ebrary Academic Complete, & World Health Organization. (2004). *Guidelines for drinking-water quality*. Geneva: World Health Organization.

*Guidelines for drinking-water quality*, 2nd ed. Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva, 1996. Retrieved from http://www.who.int/water_sanitation_health/dwq/chemicals/en/hardness.pdf

Fact Sheet – Ion Exchange. *U.S. Department of Energy.* Retrieved from http://www.netl.doe.gov/research/coal/crosscutting/pwmis/tech-desc/ionex

Feng, C., Khulbe, K. C., Matsuura, T., Gopal, R., Kaur, S., Ramakrishna, S., & Khayet, M. (2008). Production of drinking water from saline water by air-gap membrane distillation using polyvinylidene fluoride nanofiber membrane. *Journal of Membrane Science, 311*(1), 1-6.

Filtration Facts. (2005). Environmental Protection Angency. Retrieved from http://www.epa.gov/ogwdw/faq/pdfs/fs_healthseries_filtration.pdf

Florida Keys. Water quality definition. (n.d.). Retrieved December 10, 2014, from http://floridakeys.noaa.gov/ocean/waterquality.html

Food and Agriculture Organization of the United Nations, & FAO Corporate Document Repository. (2000). *Water quality management and control of water pollution: Proceedings of a regional workshop, bangkok, thailand, 26-30 october 1999*. Rome: Food and Agriculture Organization of the United Nations.

Freedman, B. (2003). Aquifer Depletion. In M. Bortman, P. Brimblecombe, & M. A. Cunningham (Eds.), Environmental Encyclopedia (3rd ed., Vol. 1, pp. 71-72). Detroit: Gale. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CCX3404800104&v=2.1&u=mlin_c_worpoly&it=r&p=GVRL&sw=w&asid=f1f5c71360bc5046fd386ea5d2269486

Gardgil, A., Greene, D., & Drescher, A. (1997). Status Report on UV Waterwork: *Water Disinfection for the Developing World*. Lawrence Berkeley National Laboratory.

Ghassemi F., Jakeman A.J., Nix H.A. 1995. Salinisation of land and water resources: Human causes, extent, management and case studies. UNSW Press, Sydney, Australia, and CAB International, Wallingford, UK.

Gheewala, S., & Silalertruksa, T., et al. (2014, June 16). Water Footprint and Impact of Water Consumption for Food, Feed, Fuel Crops Production in Thailand. Retrieved December 1, 2014, from http://www.mdpi.com/2073-4441/6/6/1698/htm

Groundwater Information Sheet: Salinity. (2010, March 1). Retrieved December 1, 2014, from http://www.waterboards.ca.gov/gama/docs/coc_salinity.pdf

Haider, Husnain. (2006). Disinfection Techniques of Rural Water Supplies in Developing Countries. *Engineering News.* 42(8&9), 9-21.

Ion Exchange Treatment of Drinking Water. (2009). *New Hampshire Department of Environmental Services.* Retrieved from http://des.nh.gov/organization/commissioner/pip/factsheets/dwgb/documents/dwgb-2-12.pdf

Johnson, R., & Tom Scherer, P. D. (2013). Reverse Osmosis. In N. D. S. University (Ed.). Retrieved from http://www.ag.ndsu.edu/pubs/h2oqual/watsys/wq1047.pdf

Kalauskas, Peter S. Student author -- RBE, Geddes, George R. Student author -- PH, Ridley, Nicholas Paul Student author -- AE, Diemand, Rebecca C. Student author -- CM, Nikitina, Svetlana Faculty advisor -- HU, & Ludwig, Reinhold Faculty advisor -- EE. (2010). *An assessment of water supply and sanitation in tsumkwe, namibia*. Worcester, MA: Worcester Polytechnic Institute.

Kim, O., & Park, H. (1998). Variation of hydrochemical characteristic of major elements in groundwater by the seawater intrusion in the Byeonsan Peninsular, Korea. *Geosystem Engineering, 1*(2), 106–110.

Knight, P. T. (2008). *Small-scale research* SAGE Publications Ltd.
Kocak, Necmettin (2011). "Water Hardness Level and It's Health Effects". *TSK Koruyucu Hekimlik Bülteni = Preventive Medicine Bulletin (1303-734X)*, p. 187.

Krabi General Information. (n.d.). Retrieved December 10, 2014, from http://www.krabi-tourism.com/krabi-general.htm

Krabi : History. (n.d.). Retrieved December 10, 2014, from http://www.thaiwaysmagazine.com/krabi/krabi_history.html

Krabi Province. (2014, October 25). In *Wikipedia, The Free Encyclopedia*. Retrieved 05:39, December 10, 2014, from http://en.wikipedia.org/w/index.php?title=Krabi_Province&oldid=631060053

Kruawal, K., Sacher, F., Werner, A., Müller, J., & Knepper, T. P. (2005). Chemical water quality in thailand and its impacts on the drinking water production in thailand. *Science of the Total Environment, 340*(1), 57-70.

Lime Softening. (2010). *U.S. Department of the Interior Bureau of Reclamation.* Retrieved from http://www.usbr.gov/pmts/water/publications/reportpdfs/Primer%20Files/07%20-%20Lime%20Softening.pdf

Marcoux, N., Martinez, J., Plumer, M., & Reni, L. (2005) Addressing Threats to Water Quality in Suan Phung Nature Education Park: Ratchaburi, Thailand. Bangkok: WPI Project Center. Worcester Polytechnic Institute.

Nettasana, T., Craig, J., & Tolson, B. (2012). Conceptual and numerical models for sustainable groundwater management in the thaphra area, chi river basin, thailand. *Hydrogeology Journal, 20*(7), 1355

Notification of the Ministry of Natural Resources and Environment :Technical Criterias and Measures to Prevent Public Health and Environment Hazard B.E. 2551 (2008), issued under the Ground Water Act B.E. 2520 (1977), published in the Royal Gazette, Vol. 125, Special Part 85 D, dated May 21, B.E. 2551 (2008). http://www.pcd.go.th/info_serv/en_re_std_water01.html#s3

Orasa, S. (1992). ELISA for Seroepidemiological Study of Exposure to Vibrio cho/erae of Population in Krabi Province, Thailand. *Asian Pacific Journal of Allergy and Immunology,* 55-60. Retrieved December 10, 2014.

Public Health Statement for Bromoform and Chlorodibromomethane. (2011). *Agency for Toxic Substances and Disease Registry.* Retrieved from http://www.atsdr.cdc.gov/phs/phs.asp?id=711&tid=128

Qiu, X., Sundin, G. W., Chai, B., & Tiedje, J. M. (2004). Survival of shewanella oneidensis MR-1 after UV radiation exposure. *Applied and Environmental Microbiology, 70*(11), 6435-6443.

Rahimpour, A., Jahanshahi, M., Mortazavian, N., Madaeni, S. S., & Mansourpanah, Y. (2010). Preparation and characterization of asymmetric polyethersulfone and thin-film composite polyamide nanofiltration membranes for water softening. *Applied Surface Science, 256*(6), 1657-1663.

Reclamation: Managing Water on the West. (2009, January 1). Retrieved December 1, 2014, from http://www.usbr.gov/pmts/water/publications/reportpdfs/Primer Files/08 - Alkalinity.pdf

Riley, J. (2011). Why Do We Need Clean Water?, Retrieved from http://www.selfgrowth.com/articles/why-do-we-need-clean-water

R.K. Goel, Bhawani Singh, & Jian Zhao. (2012). Underground infrastructures: Planning, design, and construction. US: Butterworth Heinemann

Saline Water: Desalination. (2014). Retrieved 30 November, 2014, from http://water.usgs.gov/edu/drinkseawater.html

Saraphirom, P., Wirojanagud, W., & Srisuk, K. (2013). Impact of climate change on waterlogging and salinity distributions in huai khamrian subwatershed, NE thailand. *Environmental Earth Sciences, 70*(2), 887-900.

Sata, T. (2004). *Ion exchange membranes: Preparation, characterization, modification and application*. Cambridge: Royal Society of Chemistry.

Schafer, A., Fane, Anthony, Chemical Sciences &, Engineering, Faculty of Engineering, UNSW, Waite, D., Civil &, & Environmental Engineering, Faculty of Engineering, UNSW. (2005). Nanofiltration: Principles and applications Publisher: Elsevier Advanced Technology.

Slow Sand Filtration. (2000). *National Drinking Water Clearinghouse.* Retrieved from http://www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tb/slow_sand_filtration_dwfsom40.pdf

Small Systems Treatment Technologies Biological Contaminant Removal. (2013, January 1). Retrieved December 10, 2014, from http://www.epa.gov/nrmrl/wswrd/dw/smallsystems/bcr.html

Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities. (1989). *United States Environmental Protection Agency.* Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300048WU.txt

Thailand Regional Dataset, October 2013. (2013, October 30). Retrieved December 10, 2014, from http://knoema.com/wtxids/thailand-regional-dataset-october-2013?region=1000700-krabi-province

The UV-Tube Project. (2003). *University of California at Berkeley*. Retrieved from http://rael.berkeley.edu/sites/default/files/very-old-site/uvtube/uvtubeproject.htm

Tourism Authority of Thailand. Retrieved December 10, 2014, from http://www.tourismthailand.org/Krabi

Ultrafiltration, Nanofiltration and Reverse Osmosis. (2009). In S. D. W. Foundation (Ed.). Retrieved from http://www.safewater.org/PDFS/resourcesknowthefacts/Ultrafiltration_Nano_ReverseOsm.pdf

Singh, P. N., & Wallender, W. W. (2011). Effects of soil water salinity on field soil hydraulic functions. *Journal of Irrigation and Drainage Engineering, 137*(5), 295-303.

Smedley, P. L., & Kinniburgh, D. G. Chapter 1. Source and behaviour of arsenic in natural waters (pp. 2-61). Wallingford, Oxon: British Geological Survey.

Srisuphanunt, M., Karanis, P., Charoenca, N., Boonkhao, N., & Ongerth, J. E. (2010). Cryptosporidium and giardia detection in environmental waters of southwest coastal areas of thailand. *Parasitology Research, 106*(6), 1299-1306.

Stoecker, F., Babel, M. S., Gupta, A. D., Rivas, A. A., Evers, M., Kazama, F., & Nakamura, T. (2013). Hydrogeochemical and isotopic characterization of groundwater salinization in the bangkok aquifer system, thailand. *Environmental Earth Sciences, 68*(3), 749-763.

Strathmann, H. (2010). Electrodialysis, a mature technology with a multitude of new applications. *Desalination, 264*(3), 268-288.

Srivichai, M., Supharatid, S., & Imamura, F. (2007). Recovery process in thailand after the 2004 indian ocean tsunami. *Journal of Natural Disaster Science, 29*(1), 3-12.

Suwal, S. (2014). Water In Crisis - Thailand. *The Water Project*. Retrieved from http://thewaterproject.org/water-in-crisis-thailand

Terrell, C. R. (1989). *Water quality indicators guide : Surface waters*. United States:

Thailand: Oily substance floating in krabi province's two waters canal. (2014, Oct 30). *Asia News Monitor* Retrieved from http://ezproxy.wpi.edu/login?url=http://search.proquest.com/docview/1617937418?accountid=29120

Thailand: Metropolitan waterworks authority declares tap water in bangkok safe. (2011, ). *Asia News Monitor*

Thies, Timothy Patrick Student author -- CE, McCue, Martin Fitzpatrick Student author -- MGE, Hirsch, Dylan Emory Student author -- ME, Vaz, Richard F. Faculty advisor -- EE, & Lemone, Karen A. Faculty advisor -- CS. (1999). Impact of salt production in the mahasarakham region of thailand

UN expert calls on Thailand to eliminate disparities on access to water and sanitation. (2013, February 8). *M2 Presswire*. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CA317977910&v=2.1&u=mlin_c_worpoly&it=r&p=ITOF&sw=w&asid=95e472055758dc74659810d4e72e2043

United Nations Water. (2013). *United Nations International Year of Water Cooperation: Facts and Figures* [Figure and Data File]. Retrieved from http://www.unwater.org/water-cooperation-2013/water-cooperation/facts-and-figures/en/

Wang, Gan. Water Quality : Indicators, Human Impact and Environmental Health. Hauppauge, NY, USA: Nova Science Publishers, Inc., 2013. ProQuest ebrary. Web. 15 December 2014.

Wattayakorn, G., Prapong, P., & Noichareon, D. (2001). Biogeochemical budgets and processes in bandon bay, suratthani, thailand. *Journal of Sea Research, 46*(2), 133-142.

WHO (2006) Guidelines for drinking-water quality, vol 1. World Health Organization, Genewa (PAGE 50 provides plan for safe drinking water capabilities assessment)

Worsham, David Howard Student author -- CE, Nido Rivera, Ricardo Jose Student author -- CE, Mathew, Jessica M. Student author -- CE, & Plummer, Jeanine D. Faculty advisor -- CE. (2010). *Improving drinking water quality on barro colorado island, panama*. Worcester, MA: Worcester Polytechnic Institute.

Yamamoto, K., Furumai, H., Katayama, H., Chiemchaisri, C., Puetpaiboon, U., Visvanathan, C., & Satoh, H. (Eds.). (2013). Southeast Asian Water Environment 5. IWA Publishing. (pages 27-32).

# Appendix A: Survey protocol

*Consent Script*
My name is _________ and I am a student of Chulalongkorn University and this is my partner ________ who is a university student in the United States. We would like to ask you if you would have the time to take a survey about the water uses you have at home. My team is working with the Population and Community Development Association as the sponsor to improve the current water system and water quality you have here in your village.

The purpose of this survey is to learn about the uses of water that the community has at home in order to look for potential health diseases you could probably be facing and infrastructural problems that may be caused due to the current quality of the water. We also want to know the general perception you have about the water environment in the village.

This survey is completely voluntary and we will need your consent to record the survey and take written notes. We will also need your consent to use your name in our research report, if needed. Otherwise, this survey will remain strictly confidential.

That being said, would you be willing to participate in the survey and give us your consent to record and take written notes of your responses?

*Survey Questions*

- Do you use the water from the well constructed by the PDA?
  - If no, from where do you receive your water?
- Do you feel that you have access to enough water?
  - If no, what do you think is limiting your access?
- Do you feel that the water is safe / good enough quality to be used for drinking without additional treatment like boiling?
  - If no, do you use any methods to treat your water?
    - If yes, how so?
- Do you feel it is safe enough to be directly used for cooking?
- Do you feel it is safe enough to be directly used for washing clothes or dishes?
- 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?
  - If yes, how so?
- Have you experienced any damage to your pipes or pumps, such as corrosion, mineral build up, or leaks that you feel is a result of the water quality?
  - If yes how so?
- Do you grow crops?
  - If yes, do you use the water from the well constructed by the PDA for your crops?
  - Do you feel that the water is safe to be used for this purpose?
  - Have you experienced any difficulties related to your crops, such as a decline in crop health, that you feel could be caused by the water quality?
- Do you raise livestock?
  - If yes, do you use the water from the well constructed by the PDA for your livestock?
  - Do you feel that the water is safe to be used for this purpose?
  - Have you experienced any difficulties related to your livestock, such as a decline in animal health, that you feel could be caused by the water quality?

- Are there any other difficulties you have experienced related to water supplied by the PDA?
    - If yes, what are they?

# Appendix B: Expert Interview Protocol

*Consent Script*
My name is _________ and I am a student of Chulalonkorng University and this is my partner ________ who is a university student in the United States. As you may know, our team is doing research in order to improve the current water system and water quality you have here in your village.

The purpose of this interview is to understand the current functionality of the villages' water system as well as the infrastructure and social challenges the PDA might be facing with the system.

This interview is completely voluntary and we will need your consent to record it and take written notes. We will also need your consent to use your name in our research report, if needed. Otherwise, this interview will remain strictly confidential.

That being said, would you be willing to participate in the interview and give us your consent to record and take written notes of your responses as well as to potentially use your name on our research report?

*Interview Questions*
- Could you please tell us about your position and what it is that you do?
- How does the current water system work?
- How often do you give maintenance to the system?
- Is the water being treated somehow before being distributed to the villages?
- Are you currently facing any challenges related to the current system or quality? If so, what are those challenges?
- Do you know the current properties of the water being consumed in the villages?
- Could you describe for us how the people of Baan Tha Lane and Baan Tha Thong Lang utilize the water provided by the PDA?
- Have you heard complaints from the villagers about their life quality that could be related to the water they consume? If so, what are those complaints about?
- What are the most pressing issues that are affecting these villages as you understand it?
- What resources are at the PDA's disposal to address this issue?
- Have you or the PDA worked on projects similar to this before? If so, what was the process and what ended up being the final solution?
- Given the data we have collected, what would you suggest to be our next course of action (i.e., which methods for treating water would be most effective for these areas)?
- Are there any experts you feel that we should contact to gain further information?
- Do you have any other information you wish to share?

# Appendix C: Water Quality Tables

**Table 2: Groundwater Quality Standards Outline**

| Groundwater Quality Standards | | | |
|---|---|---|---|
| Parameter | Unit | Standard Value | Analytical Methods |
| **1. Volatile Organic Compound** | | | |
| 1) Benzene | µg/l | Not exceed 5 | Purge and Trap Gas Chromatography or Purge and Trap Gas Chromatography/Mass Spectrometry or other methods approved by PCD |
| 2) Carbon Tetrachloride | " | Not exceed 5 | " |
| 3) 1,2-Dichloroethane | " | Not exceed 5 | " |
| 4) 1,1-Dichloroethylene | " | Not exceed 7 | " |
| 5) cis-1,2-Dichloroethylene | " | Not exceed 70 | " |
| 6) trans-1,2-Dichloroethylene | " | Not exceed 100 | " |
| 7) Dichloromethane | " | Not exceed 5 | " |
| 8) Ethylbenzene | " | Not exceed 700 | " |
| 9) Styrene | " | Not exceed 100 | " |
| 10) Tetrachloroethylene | " | Not exceed 5 | " |
| 11) Toluene | " | Not exceed 1,000 | " |
| 12) Trichloroethylene | " | Not exceed 5 | " |
| 13) 1,1,1-Trichloroethane | " | Not exceed 200 | " |
| 14) 1,1,2-Trichloroethane | " | Not exceed 5 | " |
| 15) Total Xylenes | " | Not exceed 10,000 | " |
| **2. Heavy metals** | | | |
| 1) Cadmium | mg/l | Not exceed 0.003 | Direct Aspiration/Atomic Absorption Spectrometry or Inductively Coupled Plasma/Plasma Emission Spectroscopy or other methods approved by PCD |
| 2) Hexavalent Chromium | " | Not exceed 0.05 | " |
| 3) Copper | " | Not exceed 1.0 | " |
| 4) Lead | " | Not exceed 0.01 | " |
| 5) Manganese | " | Not exceed 0.5 | " |
| 6) Nickel | " | Not exceed 0.02 | " |
| 7) Zinc | " | Not exceed 5.0 | " |
| 8) Arsenic | " | Not exceed 0.01 | Hydride Generation/Atomic Absorption Spectrometry or Inductively Coupled Plasma/Plasma Emission Spectroscopy or other methods approved by PCD |
| 9) Selenium | " | Not exceed 0.01 | " |
| 10) Mercury | " | Not exceed 0.001 | Cold-Vapor Atomic Absorption Spectrometry/Plasma Emission Spectroscopy or other methods approved by PCD |
| **3. Pesticides** | | | |
| 1) Chlordane | µg/l | Not exceed 0.2 | Liquid - Liquid Extraction Gas Chromatography/Mass Spectrometry or Liquid - Liquid Extraction Gas Chromatography (Method I) or other methods approved by PCD |
| 2) Dieldrin | " | Not exceed 0.03 | " |
| 3) Heptachlor | " | Not exceed 0.4 | " |
| 4) Heptachlor Epoxide | " | Not exceed 0.2 | " |
| 5) DDT | " | Not exceed 2 | " |
| 6) 2,4-D | " | Not exceed 30 | Liquid-Liquid Extraction Gas Chromatography or other methods approved by PCD |
| 7) Atrazine | " | Not exceed 3 | " |
| 8) Lindane | " | Not exceed 0.2 | Liquid-Liquid Extraction Gas Chromatography (Method I) or other methods approved by PCD |
| 9) Pentachlorophenol | " | Not exceed 1 | Liquid - Liquid Extraction Chromatography or Liquid - Liquid Extraction Gas Chromatography/Mass Spectrometry or other methods approved by PCD |
| **4. Others** | | | |
| 1) Benzo (a) pyrene | µg/l | Not exceed 0.2 | Liquid - Liquid Extraction Chromatography or Liquid-Liquid Extraction Gas Chromatography/Mass Spectrometry or other methods approved by PCD |
| 2) Cyanide | " | Not exceed 200 | Pyridine Barbituric Acid or Colorimetry or Ion Chromatography or other methods approved by PCD |
| 3) PCBs | " | Not exceed 0.5 | Liquid - Liquid Extraction Gas Chromatography (Method II) or other methods approved by PCD |
| 4) Vinyl Chloride | " | Not exceed 2 | Purge and Trap Gas Chromatography or Purge and Trap Gas Chromatography Mass Spectrometry or other methods approved by PCD |

**Table 3: Groundwater Quality Standards for Drinking Purposes**

| Ground Water Quality Standards for Drinking Purposes | | | | |
|---|---|---|---|---|
| Properties | Parameters | Units | Standards | |
| | | | Suitable Allowance | Maximum Allowable |
| Physical | 1. Colour | Platinum-Cobalt (Pt-Co) | 5 | 15 |
| | 2. Turbidity | JTU | 5 | 20 |
| | 3. pH | - | 7.0-8.5 | 6.5-9.2 |
| Chemical | 4. Iron (Fe) | mg/l | <=0.5 | 1.0 |
| | 5. Manganese (Mn) | mg/l | <=0.3 | 0.5 |
| | 6. Copper (Cu) | mg/l | <=1.0 | 1.5 |
| | 7. Zinc (Zn) | mg/l | <=5.0 | 15.0 |
| | 8. Sulphate ($SO_4$) | mg/l | <=200 | 250 |
| | 9. Chloride (Cl) | mg/l | <=250 | 600 |
| | 10.Fluoride (F) | mg/l | <=0.7 | 1.0 |
| | 11.Nitrate ($NO_3$) | mg/l | <=45 | 45 |
| | 12.Total Hardness as $CaCO_3$ | mg/l | <=300 | 500 |
| | 13.Non-carbonate hardness as $CaCO_3$ | mg/l | <=200 | 250 |
| | 14.Total solids | mg/l | <=600 | 1,200 |
| Toxic elements | 15.Arsenic (As) | mg/l | None | 0.05 |
| | 16.Cyanide (CN) | mg/l | None | 0.1 |
| | 17.Lead (Pb) | mg/l | None | 0.05 |
| | 18.Mercury (Hg) | mg/l | None | 0.001 |
| | 19.Cadmium (Cd) | mg/l | None | 0.01 |
| | 20.Selenium (Se) | mg/l | None | 0.01 |
| Bacterial | 21.Standard plate count | Colonies/$cm^3$ | <=500 | - |
| | 22.Coliform bacteria | MPN/100 $cm^3$ | <2.2 | - |
| | 23.E.Coli | - | None | - |

### Table 4: Commonly found microorganisms in water (EPA)

**Microorganisms**

| Contaminant | MCLG[1] (MG/L)[2] | MCL or TT[1] (MG/L)[2] | Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term) | Sources of Contaminant in Drinking Water |
|---|---|---|---|---|
| *Cryptosporidium* | zero | TT[3] | Gastrointestinal illness (such as diarrhea, vomiting, and cramps) | Human and animal fecal waste |
| *Giardia lamblia* | zero | TT[3] | Gastrointestinal illness (such as diarrhea, vomiting, and cramps) | Human and animal fecal waste |
| Heterotrophic plate count (HPC) | n/a | TT[3] | HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is. | HPC measures a range of bacteria that are naturally present in the environment |
| *Legionella* | zero | TT[3] | Legionnaire's Disease, a type of pneumonia | Found naturally in water; multiplies in heating systems |
| Total Coliforms (including fecal coliform and *E. Coli*) | zero | 5.0%[4] | Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5] | Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste. |
| Turbidity | n/a | TT[3] | Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (such as whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches. | Soil runoff |
| Viruses (enteric) | zero | TT[3] | Gastrointestinal illness (such as diarrhea, vomiting, and cramps) | Human and animal fecal waste |