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# A Cultural and Technical Study of Wastewater Treatment Plant Maintenance in a Small Community in Peru

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# A CULTURAL AND TECHNICAL STUDY OF WASTEWATER TREATMENT PLANT MAINTENANCE IN A SMALL COMMUNITY IN PERU

By

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# Table of Contents

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## Abstract

Management of wastewater treatment plants (WWTPs) has been found to be especially challenging in small, rural communities of the developing world. This study examined maintenance of two small WWTPs in Leymebamba and Palmira, Peru through interviews with local authorities, observation of maintenance practices, wastewater measurements, and prediction of effects from maintenance with modeling using a wastewater process simulation software, BioWin. Challenges and motivations related to maintenance were investigated with semi-structured interviews, and maintenance practices were recorded during observations. It was found that outside supervision was a key motivating factor, and the existence of an operator who is supported by the administration was important as well. The maintenance practices in Leymebamba and Palmira were graded with a quantitative scale and were given 35% and 22% of the possible points, respectively. Measurements of influent and effluent biochemical oxygen demand (BOD) and total suspended solids (TSS) were taken at the plants, and the removals were estimated using the measurements. A BioWin model was developed based on the Leymebamba WWTP, and its performance was compared to that of the actual plant. The BioWin model performed over one standard deviation below the mean with respect to the plant's average BOD removal, and it performed within one standard deviation of the mean with respect to the plant's average TSS removal. The effects of maintenance were simulated in BioWin, and it was found that the performance was not significantly impacted by the alternate maintenance scenarios. However, maintenance is still recommended to prevent undesirable environmental problems and keep the WWTPs in working condition. The BioWin software was found to have limitations when modeling Imhoff tank systems with low maintenance, and future work is needed to further explore maintenance scenarios described in this study.

# 1: Introduction

As the global population increases, the effects of poor wastewater management become more severe. Lack of proper treatment of wastewater leads to spread of water-borne diseases, pollution of water bodies, and harm of aquatic life. In low- or middle-income countries, 842,000 deaths in 2012 were estimated to have been caused by inadequate water, sanitation, and hygiene practices (Pruss-Ustun, Bartram et al. 2014). Eutrophication of water bodies, including dead zones along coastlines and harmful algal blooms, is partially caused by the excessive nutrients from discharged wastewater (UNEP 2001). This problem is exacerbated in the developing world, where the population is rapidly growing and in many areas, depleting fresh water supplies at an unsustainable rate.

Progress is being made globally to ensure sewage treatment or at least separation from human contact. During the Millennium Development Goal period, it was estimated that use of improved sanitation facilities rose from 54 to 68 percent globally (UNICEF and WHO 2015). Of these sanitation facilities, some are sewage systems constructed in urbanized areas, and some of these sewage systems have wastewater treatment plants (WWTPs) to treat the sewage before it enters water bodies. It was estimated that 14% of the global population was connected to a sewage system with a treatment plant in 2010, while 22% is connected to a sewage system with no treatment (Baum, Luh et al. 2013). As the Millennium Development Goal results indicate, more people globally are improving their sanitation facilities. Thus, communities with new facilities are encountering the challenge of managing their facilities. Small, rural towns undergoing this process have unique barriers to providing adequate wastewater management.

## 1.1: Challenges of Wastewater Management in Small, Rural Towns

3.37 billion people in the world still live in rural areas, most of those being in less-developed countries (UN Dept of Economic and Social Affairs Population Division 2014). Much of the global rural population is scattered and uses decentralized sanitation systems such as pit latrines and septic systems, or simply practices open defecation. Small towns in rural areas are often in difficult situations because they are large enough to have the economies-of-scale necessary for sewage collection systems and centralized treatment, but they are too small to have the human resources to manage them.

There are many specific challenges that previous literature has found with regards to rural WWTP management.

Prior studies show that for a technology to succeed, it has to be appropriate in its cultural and economic context. In many instances, the government or aid agency constructed WWTPs that were too complex or costly for their communities to handle. This included WWTPs that required electricity installed in locations with frequent power shortages or that simply could not afford the electricity costs (Murray and Drechsel 2011) (Massoud, Tareen et al. 2010). Similarly, an upflow anaerobic sludge blanket (UASB) reactor built for a small Bolivian town was too complex and expensive for the operator to maintain and was inoperative within four years of its construction (Cairns 2014). In one study, engineers in a region of Mexico chose a particular type of WWTP because of their familiarity with the technology and did not examine its effectiveness or appropriateness (Haase 2010).

Another common issue has been poor design and construction of the WWTPs. Due to outdated engineering calculations, lack of key information about the people served, corruption, or being overshadowed by other priorities, these systems are often improperly sized or left unfinished. In a study of seven small WWTPs in Honduras, many were found to be unfinished, and one was overloaded four times its design flow because of illegal connections and coffee depulping, in which community members would run their taps through the night (Mikelonis, Herrera et al. 2010). A similar study of 10 plants in Mexico showed that the design criteria used to size units was not technically based and led to clogging and failure in less than five years after construction (Haase 2010).

Any water or sanitation system, no matter how simple, will need maintenance to continue functioning. Rural communities often are not organized enough to provide maintenance to WWTPs, as this requires funds and the ability to pay and train an operator. Many surveys of WWTPs have found that presence of maintenance personnel to be a strong indicator of plant functionality (Murray and Drechsel 2011) (Mikelonis, Herrera et al. 2010) (Massoud, Tareen et al. 2010). However, even when there was an operator, such as with the UASB reactor in Bolivia, he was overworked from the responsibilities of maintaining both the water and wastewater systems, and he did not receive enough support from his administrative group (Cairns 2014).

The community's opinion and awareness of the WWTP has been found to be an important factor in the plant's success, especially economically. When a small town in Guatemala received a modern WWTP and sewer system, the citizens did not see the importance of changing their previous behavior and paying to connect to the system (Ratner and Rivera Gutiérrez 2004). A study in Bolivia found that sanitation projects which had invested more in training the community got more buy-in and understanding from the community members (Fuchs and Mihelcic 2011). Constant turnover of local government and water committees increases the likelihood that new administrations will forget about the plants, leaving them unattended for months (Haase 2010).

Accountability is a crucial factor for WWTPs to stay maintained. This includes accountability of the operator to the administration group, accountability of the benefitting community to the agency which constructed the plant, and/or accountability to an environmental protection group. Studies have found that when more accountability is present, it is more likely that plants are operational (Murray and Drechsel 2011) (Massoud, Tareen et al. 2010).

## 1.2: Project Background and Overview

The author served as a Peace Corps volunteer in Leymebamba, Peru for two years, working in the Water, Sanitation, and Hygiene program, while simultaneously enrolled in the Peace Corps Master's International program. She chose to study the wastewater treatment plants in her site, focusing on maintenance, because she wanted to understand how well the communities were able to perform maintenance, and how maintenance impacted performance. In previous studies, maintenance was found to be an important factor in the functionality of WWTPs (Murray and Drechsel 2011) (Mikelonis, Herrera et al. 2010) (Massoud, Tareen et al. 2010). However, few studies looked into both social and technical aspects of WWTP maintenance. It is important to look at both aspects because maintenance is inherently a social and technical issue, and looking at it simply through one lens does not allow full understanding of the challenges and effects of maintenance. Few studies were able to make observations over a longer period of time. Living in the town for two years and actively studying the plants for six months allowed a deeper analysis of the factors and people involved in wastewater management and plant maintenance. She observed the maintenance performed on the plants, which would inform her how the operators were interacting with the WWTP. The author performed semi-structured interviews with key informants to learn about their challenges, which would inform her about the social and cultural context in which the study took place. She decided it was not only important to find the qualitative and cultural data, but also important to see how well the plant was performing and fulfilling its function as a wastewater treatment system. She tested treatment quality parameters to estimate the performance of the system. After the tests, she wanted to be able to find how the maintenance practices would affect the performance of the plant, so she created a computer model of the system to predict the effect that different maintenance practices would have on the performance. Combining the different elements into the study allowed for a holistic view on maintenance in a rural community.

## 1.3: Study Objectives

1. Observe maintenance practices in two WWTPs in Leymebamba, Peru between May and November 2015
2. Describe motivations and challenges of operators and local authorities related to maintenance of WWTPs
    2.1. Collect information from key informants using semi-structured interviews and informal conversations
    2.2. Organize and summarize common themes from data, including motivations and challenges
3. Collect data measuring influent and effluent BOD and TSS values in study WWTPs
4. Model WWTP in BioWin to find expected treatment of study WWTP under different maintenance scenarios
    4.1. Develop BioWin model of WWTP in Leymebamba and compare modeled BOD and TSS reduction to measured results
    4.2. Evaluate sensitivity of model outputs to key operating parameters.
    4.3. Using the model and field observations, create different maintenance scenarios and compare results to measured and literature results

## 1.4: Description of Study Area

### 1.4.1: Leymebamba, Amazonas, Peru

Peru is a South American country of 30.4 million people where the primary language spoken is Spanish and the primary religion is Roman-Catholicism (CIA 2015). Peru was home to many ancient cultures, the most well-known of which was the Incan empire, before being conquered by the Spanish in the 1500s, from whom independence was gained in 1821 (Encyclopædia Britannica 2016). There are three main climatic zones – the coast, highlands, and Amazon rainforest (PROM Peru). Figure 1.1 shows Peru with the location of the study area Leymebamba indicated.


*Figure 1.1: Location of study area. Map of Peru showing political boundaries, bordering countries, and main geographical features. Pin indicates location of Leymebamba and star indicates location of capital city Lima. Image adapted from Wikimedia Commons, created by users Spischot and Huhsunqu.*

The study was done in the region of Amazonas and in the district of Leymebamba. The area is classified as lower highlands transitioning into rainforest. The altitude of the Leymebamba town plaza is 2203 meters, or 7228 feet, above sea level (Elevation.net). The average temperature is 16.1 °C (61.5°F), the average rainfall per year is 31.7 inches, and the climate in Leymebamba is characterized by a rainy season from October to April and a dry season from May to September (Climate-data.org). The district capital and largest town is Leymebamba. The smaller community of Palmira is in the district as well and was also part of this study. Leymebamba and Palmira are situated in a valley through which the Utcubamba River flows. The terrain is steep and rocky. The urbanized centers are mostly on flat land near the river, with fields for farming in the surrounding hills, as shown in Figure 1.2.

*Figure 1.2: The town of Leymebamba. Palmira is visible in the distance as well. Photo by Megna Saha.*

The district has a population of 4,190 (INFOgob). The population of the town of Leymebamba is about 2,300 people, and the population of Palmira is about 800, based on local estimates. The economy is largely based on agriculture, cattle-raising, and milk production. Other industries include construction and tourism. A minor highway passes through Leymebamba, connecting the two regional capital cities of Chachapoyas and Cajamarca. Public transportation by van is available multiple times per day from Chachapoyas, the drive being a little under two hours. The most economical way to get to Chachapoyas from Peru's capital, Lima, is a 22-hour bus ride. The district is located in an area which was once inhabited by the pre-Incan culture known as the Chachapoya, which was present from ca. 800 AD until they were overtaken by the Inca in the mid to late 1500s (Church and Von Hagen 2008). Ruins from the Chachapoya still can be found in the area. There is a museum that houses more than 200 mummies found in cliffs alongside a nearby lake (Von Hagen and Guillén 1998). La Congona, la Petaca, la Boveda, and Diablo Huasi are other Chachapoyan ruins that can be reached from Leymebamba. The Chachapoyan and Incan cultures have also left remnants in the society. Although Spanish is spoken by almost 100% of the population, Chachapoya and Quechua words have been blended into the daily language. Local traditions include weaving, performing Yaraví songs, and preparing traditional dishes such as fried guinea pig with stewed potatoes. Along with those older traditions, many typical Latin American customs are practiced in Leymebamba. For example, the people gather to watch and play soccer and volleyball, especially on Sunday afternoons. Other pastimes include spending time with family, dancing, drinking, and chewing coca leaves. The religion practiced is mostly Roman Catholic, with a variety of Protestant sects represented as well. Every year the towns' patron saints are celebrated with a two-week festival. The urban centers of the district enjoy many modern technological developments – paved roads, electricity, cell service, internet cafes, cable television, shops, restaurants, bakeries, a health center, public schools, public transportation, and water and wastewater services.

Leymebamba and Palmira are separated by a distance of about 1 kilometer. The Utcubamba River flows between them, creating a physical barrier. Although they are close, each has their own drinking water and wastewater system. The sources of their water supplies are from mountain springs in different cordilleras, each over 15 km distance away and almost 1 km higher in altitude than Leymebamba. The drinking water systems are gravity-fed, utilizing a number of pressure-break chambers and valves to bring the water down the mountain, and are without treatment processes other than sedimentation and chlorine addition in Leymebamba. Additionally, each community has their own wastewater collection and treatment system. Both communities use conventional gravity sewers with no lift stations. In Leymebamba, there are approximately 700 homes, and in Palmira, there are approximately 250 homes. In both communities, about 95% percent of the homes are connected to the sewer systems. There are several small businesses such as restaurants, auto mechanics, offices, etc., especially in Leymebamba, but the wastewater is primarily generated from domestic activities. The systems were constructed using regional government funds, but each community had to provide means of administrating, operating, and maintaining them. As of 2015, when this study was performed, Leymebamba had a municipal water and sanitation administration and Palmira had a water committee administration.

### 1.4.2: Administration of Water and Wastewater Services in Peru

Peruvian law dictates that communities of under 2000 residents should have a voluntary water committee and provides guidelines on its establishment and governance (Programa AguaLimpia FOMIN 2013). The water committee is intended to be democratic with elections and major decisions made at general assemblies. The water committee is required to be run by a board that includes a president, secretary, treasurer, two spokespeople, and a supervisor who is not officially in the board but is tasked with auditing the other members. In the general assembly, the cost of the monthly water bill is voted on. With the money raised from this bill, the operation and maintenance costs – including tools, materials, and operator wages – should be covered. It is the committee's responsibility to contract and supervise the operator.

In contrast, Peruvian communities of 2000 residents or more should delegate responsibilities of water and sanitation to the district municipality (PNSR 2015). This setup uses a top-down approach; the municipality decides the water bill cost, contracts operators, creates rules, etc. without the required approval of the users. The municipalities are given government funds to provide services to their constituents, such as sanitation, roads, social services, and civil records. These funds are managed by the treasurer. In contrast, water committees have only the funds from their water bill or any additional charges to the user, such as installation fees. Another potential advantage is that district municipalities in recent years are creating a Municipal Sanitation Department (in Spanish: Área Técnica Municipal de Saneamiento), which is a department of the municipality designated to manage the water and sanitation services in the district (PNSR 2015). This includes supporting smaller communities and water committees in their district along with working in the district capital. Depending on the population of the district, the Municipal Sanitation Department (MSD) could just be one person, who may or may not have other responsibilities in the municipality.

At the time of the study, Palmira had a water committee that was initiated in 2001. A new board was elected every two years. The board members included a president, vice president, secretary, treasurer, spokesperson, and supervisor. Leymebamba had recently changed in 2013 from using a water committee to administrate their water services to the municipality. They had an MSD staffed with one person, who will be henceforth referred to as the MSD.

### 1.4.3: Wastewater Treatment in Peru and the Amazonas Region

Especially in recent years, Peru has significantly increased its coverage of wastewater treatment and sanitation. For the larger cities in Peru in which private companies provide water and sewer services to about 62% of the country's population, it was reported in 2010 that 76% of their clients were connected to the sewers, and 35% of the sewage generated was treated (FONAM 2010). In recent years, the city of Lima has expanded its wastewater treatment works to receive 10,000 additional liters of sewage per second (Perú21 2014), so that now potentially 75% of the sewage in the larger cities is being treated.

In rural regions such as Amazonas, there has been increasing wastewater treatment coverage as well, although there may not always be the support needed to maintain the facilities. The district capital towns in southern Amazonas have populations similar to Leymebamba's – between 500 and 5000 people. Of the 37 towns that discharge their wastewater into the Utcubamba River watershed, 30 or about 81% of the towns have constructed WWTPs (ALA Utcubamba 2014). At least eight of these systems were found to be abandoned. Other systems were known to be poorly or not maintained.

### 1.4.4: Wastewater Regulations in Peru

The Peruvian institutions that are involved with wastewater-related issues are the National Water Authority, the Environmental Evaluation and Investigation Institution, and the Environmental Prosecutor. The National Water Authority manages water resources and authorizes the discharge of wastewater into water bodies (Autoridad Nacional del Agua 2013). The Environmental Evaluation and Investigation Institution supervises wastewater treatment from industrial activities such as mining, petroleum extraction, and manufacturing (OEFA 2014). The Environmental Prosecutor inspects sanitation facilities such as wastewater plants, landfills, and medical waste facilities to ensure they are in operation (Asenjo Bustamante 2015).

There is legislation regarding effluent quality in Peru. The Ministry of the Environment published maximum permissible limits for effluents of municipal or domestic WWTPs, which is shown in Table 1.1 (Ministerio de Ambiente 2010). Additional legislation describes how often WWTPs must be tested and their parameters reported (SUNASS 2015). The frequency of the testing depends on the quantity of flow from the plant. It is unknown if these limits are enforced for smaller systems such as Leymebamba and Palmira, but it seems that testing is at least required for larger systems. Other laws regulate the quality of water after the discharge point of the wastewater and the quality of industrial wastewater that is discharged into public wastewater collection systems (SUNASS 2015). In Table 1.1, the maximum permissible limit values are shown and compared to the maximum 7-day average limits for BOD, TSS, and pH as described in the United States Code of Federal Regulations (40 CFR 133.102 1984). As expected, the maximum values in Peru are much higher than what is allowed in the United States for BOD and TSS.

| Parameter | Unit | Peru Maximum Permissible Limits | USA Secondary Treatment Regulations (7 day Average) |
|---|---|---|---|
| Oils and Fats | mg/L | 20 | - |
| Thermotolerant Coliforms | MPN/ 100 mL | 10,000 | - |
| Biochemical Oxygen Demand | mg/L | 100 | 45 |
| Chemical Oxygen Demand | mg/L | 200 | - |
| pH | unit | 6.5-8.5 | 6-9 |
| Total Suspended Solids | mg/L | 150 | 45 |
| Temperature | °C | 35 | - |

*Table 1.1: Maximum permissible limits for municipal or domestic WWTP effluents in Peru alongside United States secondary treatment regulations' maximum effluent levels using the 7-day average limits.*

## 1.5: Wastewater treatment Systems in Leymebamba, Peru

### 1.5.1: Small-Scale Wastewater Treatment Technologies

Due to rural, developing communities having generally low economic resources and lack of skilled workers, their wastewater treatment technologies are usually simple, requiring minimal energy inputs and maintenance. A primary goal of these systems is removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) (Sasse 1998). BOD is the amount of oxygen consumed by organisms when breaking down organic substances in water. COD is the amount of oxygen required to oxidize the chemicals in the water. TSS is the solid content in wastewater which can be caught in a filter. BOD and TSS were the two parameters used in this study to measure plant performance because the WWTPs are designed to remove them. Other contaminants such as coliform, nutrients, and metals are also removed because they are attached to solids which settle out; however, there is no treatment processes specifically targeting those contaminants in the study WWTPs. Common simple wastewater treatment technologies are stabilization ponds, septic systems, trickling filters, and Imhoff tanks (Sasse 1998). These technologies provide preliminary, primary, and sometimes secondary treatment. Preliminary wastewater treatment is the removal of large solids and grit to protect units and promote better treatment later in the plant. Primary treatment is the removal of settleable solids by sedimentation and skimming of the floating solids. During the removal of these solids, the bacteria and nutrients attached to those solids are removed as well. Secondary treatment involves the use of biological processes to further remove organic material and suspended solids (FAO 1992). The most common technologies used in southern Amazonas were stabilization ponds and septic systems/soak pits (ALA Utcubamba 2014). In both Leymebamba and Palmira, Imhoff tank systems were built. It could be speculated that this system was chosen because it did not require as much space as a stabilization pond, and it would treat a larger wastewater flow than a septic system. The processes were all gravity-fed; no pumps were used, and all the cleaning had to be performed manually. Because Leymebamba is more than two times larger than Palmira, the units were noticeably larger and designed slightly differently.

The wastewater treatment system in Leymebamba and Palmira consisted of preliminary, primary, and secondary treatment processes. The preliminary treatment was a bar screen and grit chamber unit. The primary treatment was an Imhoff tank. The secondary treatment was a trickling filter. The sludge from the Imhoff tank was removed and dried in the sludge drying beds. The effluent was discharged to the Utcubamba River. Figure 1.3 is a schematic of the system. The components of the system are further described in the following section.

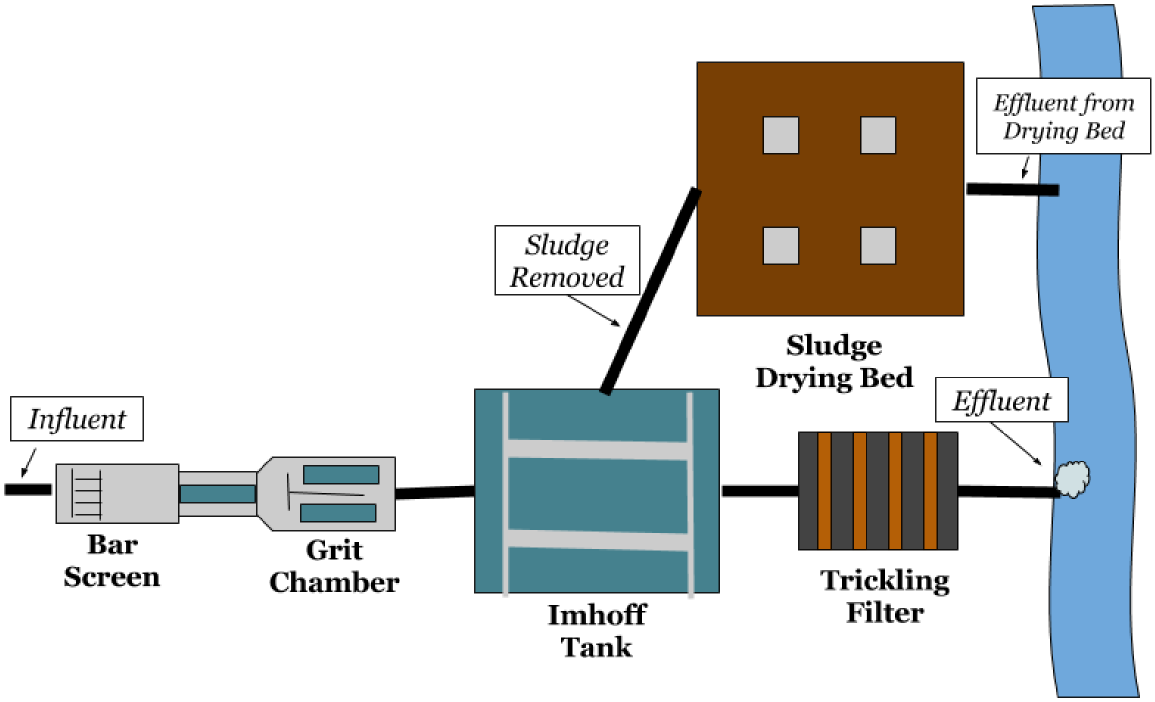


*Figure 1.3: Schematic of WWTPs in Leymebamba and Palmira.*

### 1.5.2: Wastewater Treatment Systems by Unit Process

*Bar Screen*

The first step in the preliminary treatment of the raw wastewater after it reaches the plant is to screen out large objects such as trash, branches, rocks, and even small animals by using bar screens (EPA 2003). The bar screens in Leymebamba and Palmira required manual cleaning and were designed with a bypass in case the screens were left uncleaned to avoid clogging and obstruction of flow. The bar screen was built in the same unit as the grit chamber, and both are displayed in Figure 1.4.

*Grit Chambers*

After the bar screens take out large debris, the grit chambers remove the larger sediment that can easily settle. This "grit" has greater specific gravity than most organic biodegradable solids. The plants in the study used horizontal-flow grit chambers, which have two long chambers that are typically designed to slow the velocity of the water to at least 0.3 m/s (EPA 2003). The chambers have gates that can be used to control the flow. One chamber can be cleaned while the other is still operational.

After the grit chamber in the Leymebamba plant, there is a Cipolletti weir with a free-fall drop that can be used for flow measurement as well as providing natural aeration (Bagatur 2009). A weir was not included in the Palmira design.

*Figure 1.4: Preliminary treatment unit in Leymebamba WWTP. Left image shows whole unit with bar screen in foreground. Right image shows grit chamber. Photos by author.*

### *Imhoff Tanks*

Imhoff tanks are primary wastewater treatment units that use both sedimentation and anaerobic digestion processes to clarify wastewater and stabilize the settled solids (Crites and Tchobanoglous 1998). The Imhoff tank was patented in 1906 by Dr. Karl Imhoff, and it was widely used in the 1930s-40s in the United States (Asmus 2005). They can be found all over the world. In developed countries, they do not usually meet effluent requirements, so they have often been retrofitted to have automated controls and mechanical cleaning mechanisms (Asmus 2005). In developing countries, especially in smaller communities, Imhoff tanks are still being constructed and used as the principal wastewater treatment unit, sometimes without preliminary or secondary treatment. The Imhoff tank in Leymebamba is shown in Figure 1.5.

Imhoff tanks have four chambers where different processes occur. The wastewater first enters the sedimentation chamber, where the flow slows to provide a design hydraulic retention time of 2-4 hours (Crites and Tchobanoglous 1998). During this time, most of the suspended solids pass down through a small slot in the bottom of the sedimentation chamber and settle in the digestion chamber (Tilley, Ulrich et al. 2014). The solids undergo a process of anaerobic digestion in which organisms break down organic material and produce biogas in an environment without oxygen (WEF 2008). Digestion rates are dependent on temperature (WEF 2008). The digestion chamber is designed to collect sludge for a long enough time to allow the digestion processes to occur at the local temperature, which is an annual average of 16.1 °C (Climate-data.org).

During the settling process, the solids separate into sludge, which sinks to the bottom, and scum, which floats to the top. The scum cannot rise back up to the sedimentation chamber and instead goes around the sides to the scum chambers, which are on both sides of the sedimentation chamber (Crites and Tchobanoglous 1998). The Imhoff tank's separate chambers allow these processes to occur without disturbing the other processes.

*Figure 1.5: Imhoff tank in Leymebamba. The middle chamber is the sedimentation chamber, the sides are scum chambers, and the bottom which is not visible is the digestion chamber. Photo by author.*

Imhoff tank performance has been found to be variable. They can be compared to a primary clarifier in terms of BOD and TSS removal. On average, it is said that they remove about 25-50% of the BOD and 50-70% of the TSS in the wastewater (Sasse 1998) (Tilley, Ulrich et al. 2014). Various studies have found 15-82% removal of BOD and 20-60% removal of the TSS (Korsak and Moreno 2006) (McLean 2009) (Chuchón Martínez and Aybar Escobar 2008) (Hatfield and Morkert 1932) (Bécares, Soto et al. 2009) (Texas Water Commission 1991). These results are presented in Table 1.2. Difference in variables such as temperature and maintenance practices make it difficult to elucidate why these systems achieved different results.

| **Author** | **Location** | **Removal Rates** | | |
|---|---|---|---|---|
| | | **BOD** | **COD** | **TSS** |
| Korsak and Moreno (2006) | Nicaragua | 82% | | |
| McLean (2009) | Honduras | | 8% | |
| Chuchón and Aybar (2008) | Peru | 28% | | |
| Hatfield and Morkert (1932) | Illinois, USA | | | 55% |
| Bécares et al (2009) | Spain | 15% | 6% | 20% |
| Texas Water Comm. (1991) | Texas, USA | 30% | | 60% |

*Table 1.2: BOD, COD, and TSS removal rates from Imhoff tank systems in literature.*

*Trickling Filters*

After the wastewater has undergone primary treatment in the Imhoff tank, the flow is directed to the trickling filters for secondary treatment. Trickling filters are rock beds where the wastewater is usually sprayed or dosed intermittently. A film of bacteria grows on the rocks, and as the wastewater trickles through the bed, the bacteria consume its organic material and pathogens (Crites and Tchobanoglous 1998). The trickling filter used in Leymebamba, Palmira and other parts of Peru and Bolivia (Ministerio de Agua Bolivia 2007) is a specialized version that is not well-described in current literature. It is a rectangular or square concrete structure with many perforated metal or plastic channels running across the top, as seen in Figure 1.6. The pre-treated water enters at one side and continuously flows through the channels over the rock media bed.

*Figure 1.6: Trickling filter in Palmira WWTP. Photo by author.*

*Sludge Drying Beds*

The sludge in the Imhoff tank usually needs further treatment after to remove more pathogens before it can be safely disposed or used in agriculture. For this reason, many Imhoff tanks, including the ones in Palmira and Leymebamba, have sludge drying beds. Figure 1.7 shows one of these beds. The sludge is removed by gravity from the tank through a pipe. The operator controls a valve to release the sludge. The sludge usually comes out as mostly water and partially fills up the beds. The water passes through granular layers and collects in a trench below the beds. From there, the water flows out and is discharged into the river. The solids are left to dry. Once the sludge is dried and removed, it can be buried or used for certain agricultural purposes (Fondo Multilateral de Inversiones and AguaLimpia 2013).

*Figure 1.7: Sludge drying beds in Leymebamba. Photo by author.*

The dimensions of the units in the WWTPs in Leymebamba and Palmira, as measured or estimated, is shown in Table 1.3. Some of these values were used in later sections of this report.

| **Treatment Unit** | **Dimension** | **Unit of Msmt** | **Value** | |
|---|---|---|---|---|
| | | | **Leymebamba** | **Palmira** |
| Influent | Flow | $m^3/d$ | 290 | 120 |
| Bar Screen | Number of Bars | number | 10 | 5 |
| | Spacing between Bars | cm | 5 | 5 |
| Grit Chamber | Length of Chamber | m | 5 | 2 |
| | Width of Chamber | m | 0.75 | 0.3 |
| Imhoff Tank | Volume of Sedimentation Chamber | $m^3$ | 40 | 15 |
| | Volume of Scum Chambers | $m^3$ | 50 | 60 |
| | Volume of Digestion Chamber | $m^3$ | 180 | 90 |
| Trickling Filter | Surface Area | $m^2$ | 36 | 15 |
| | Depth | m | 2 | 1 |
| Sludge Drying Beds | Surface Area | $m^2$ | 250 | 100 |

*Table 1.3: Approximate dimensions of treatment units in Leymebamba and Palmira*

### 1.5.3: Maintenance Recommendations

The WWTPs in Leymebamba and Palmira were designed to be maintained regularly. With each unit process, recommendations for maintenance and frequency of maintenance have been established (Fondo Multilateral de Inversiones and AguaLimpia 2013) (Texas Water Commission 1991). Most of these recommendations are specifically aimed at Peruvian WWTPs. Some have been suggested for American Imhoff tanks but would be useful for Imhoff tanks anywhere. The recommendations are summarized in Table 1.4 below.

| Unit | Maintenance Task | Frequency |
|---|---|---|
| Bar Screen | Remove solids | Daily |
| Grit Chamber | Remove solids | Weekly |
| Imhoff tank | Clean the slot with a chain | Weekly |
| | Remove the scum and floating solids | Daily |
| | Scrape the solids from the walls | Weekly |
| Trickling Filter | Verify that it is functioning properly | Monthly |
| Sludge Drying Beds | Remove plants | Every few months |
| | Remove and dispose of dried sludge | Before de-sludging |
| | Purge solids into the sludge drying beds | Every 60-75 days |
| General Site | Dispose of waste appropriately | Daily |
| | Keep vegetation trimmed | Every few months |

*Table 1.4: Maintenance recommendations for WWTP units.*

# 2: Methodology

## 2.1: Methods of Qualitative Data Collection and Analysis

To gain understanding of the maintenance and use of the wastewater treatment plants in Leymebamba and Palmira, different qualitative data collection methods were used. These methods were observation of conditions at the WWTPs, semi-structured interviews with key informants, and conversations and interactions with community members regarding the WWTPs. The maintenance practices were analyzed using month-by-month evaluations based on recommended practices. Motivations and challenges were analyzed from the interviews and field notes collected using the coding method, which is a qualitative data analysis method in which labels are assigned to different themes in a data set, and then the data is reorganized to further explore or analyze certain themes (Strauss and Corbin 1998). Finally, qualitative results were used to build the model and maintenance scenarios in the next stage of the study.

Observations were made and relationships were built in the community for over a year before the study began. Permission was obtained formally from the district mayor, and the study was informally discussed with participants before gaining official consent. The Institutional Review Board at Michigan Technological University gave approval to perform the study, number M1351, as seen in Appendix A. The nine key informants that were interviewed were already either working for the local government in the water and sanitation administration in Leymebamba or were in Palmira's water committee. There were no other people directly involved in water and sanitation issues at that time, but informal conversations with people who had formerly been involved or were indirectly involved also proved informative. The nine key informants participated in semi-structured interviews about the plant, their work, their administration, and the history of the plant. The questions were varied slightly depending on the duties of the interviewee - operator, committee member, etc. Detailed notes were taken on these interviews to be analyzed in the study. The interviews were conducted by the author in Spanish. The questions and consent documents were written using common language and checked with a native speaker for understanding. These documents can be found in Appendices B and C.

Additionally, information was gathered from informal conversations or meetings with key informants or other community members whenever the WWTPs or the administrations were discussed. Typical data gathered included information about maintenance, conflicts, and challenges in the administration of the sanitation services. This information was recorded in the author's research journal and coded for analysis.

Observations of the WWTP conditions were recorded at various points in the study, especially when samples were taken from the plant. The plant conditions were described in the author's research journal or were captured with photographs.

The information gathered from the interviews and research journal was coded with different themes and organized for analysis. Challenges faced by the water administrations were the main focus, and these challenges were tied to maintenance deficiencies, as compared to the established recommendations (Fondo Multilateral de Inversiones and AguaLimpia 2013). These maintenance deficiencies were the basis of the scenarios for modeling the WWTP. No names were used in the discussion of the results, only job titles. For understanding, "Operator 1" and "Operator 2" refers to Leymebamba's primary and secondary water and sanitation operator, respectively. "MSD" refers to the person in charge of Leymebamba's Municipal Sanitation Department. For Palmira, committee roles such as president, vice president, secretary, treasurer, spokesperson, supervisor, and board member will be used instead of names.

## 2.2: Methods of Wastewater Sampling and Testing

The influent and effluent wastewater at the two WWTPs in Leymebamba, Peru were sampled and sent to a NKAP Laboratory, a private Peruvian laboratory in the city of Cajamarca, where the samples were tested for $BOD_5$ and TSS.

The author went to the plants on fair weather days in the mid-afternoon and using gloves and a cup, filled a 1-L container with the influent taken from the very beginning of the plant, before preliminary treatment. She repeated the process to collect effluent at the discharge point. The same process was done at the next plant, and the four 1-L wastewater containers were put in a cooler with ice packs and sent on a night bus to Cajamarca, 10 hours away. The containers had to reach the lab within 24 hours. The laboratory personnel picked up the cooler the next morning, within 18 hours from the sampling. This process was completed on five separate occasions between August and

November. All tests were done in coordination with the laboratory, and the laboratory provided the materials – containers, coolers and ice packs.

The laboratory used Standard Methods for the Examination of Water and Wastewater APHA-AWWA-WEF, $22^{nd}$ Ed. 2012 Part 2540 A and D for TSS and Part 5210 A and B for BOD. Within about two weeks the results were emailed to the author.

## 2.3: Methods of BioWin Modeling

### 2.3.1: BioWin Modeling Software

The WWTP in Leymebamba was modeled using BioWin, a program developed by EnviroSim for wastewater treatment process simulation. It is used worldwide to design and analyze WWTPs (EnviroSim 2016). The most common plants that are modeled by BioWin are North American conventional municipal WWTPs, but the program has been used, albeit in few occasions, for simpler systems such as decentralized wastewater treatment units in Haiti and a facultative lagoon in Canada (Sönmez, Tengnäs et al. 2011) (Houweling, Bye et al. 2008). No literature was found in which Imhoff tanks were modeled using BioWin – this is a contribution of this research.

### 2.3.2: Properly Maintained Base Model

Information about the WWTP in Leymebamba was used to create a BioWin model. The base model used the dimensions of the units, flow estimations, measured BOD and TSS concentrations, and literature values as inputs of the various BioWin elements. Table 2.1 shows relevant values input into the BioWin model and the sources of those values. The treatment process of the model began after the preliminary treatment, followed by the Imhoff tank and trickling filter, then finished at the outlet. As the Imhoff tank was not a BioWin standard element option, a variety of other elements were used to simulate the effect of an Imhoff tank. Figures 2.1 and 2.2 show the flow process in the theoretical Imhoff tank and then as simulated in the BioWin model.

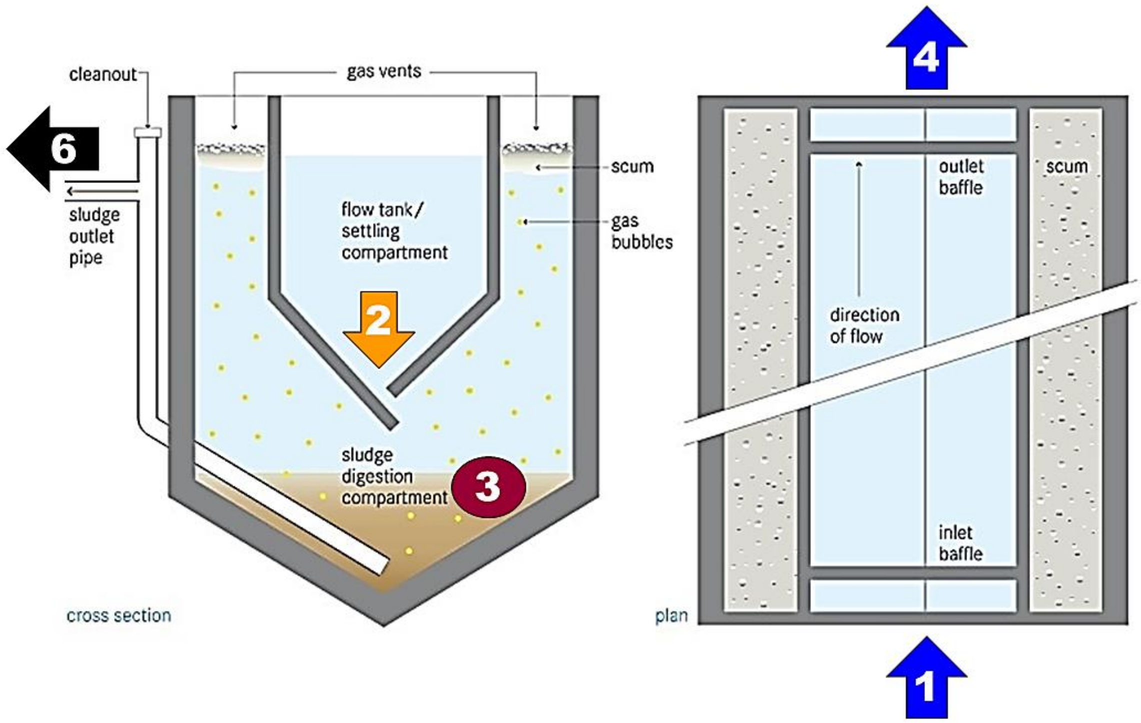


*Figure 2.1: Imhoff flow schematic, showing liquid flows and settling. Explanation of each step:*

1. *Wastewater flows after preliminary treatment to Imhoff tank.*
2. *Solids settle down through slot in sedimentation chamber.*
3. *Solids undergo anaerobic digestion in lower chamber. Some float up to the scum layer.*
4. *Wastewater leaves Imhoff tank and goes to trickling filter.*
5. *(not shown above) Wastewater leaves trickling filter and is discharged.*
6. *Digested solids are removed from digestion chamber.*

*Image adapted from Eawag (2014): eCompendium.*

A BioWin model was created in attempt to simulate this flow process as accurately as possible. Figure 2.2 below shows the diagram of this model.

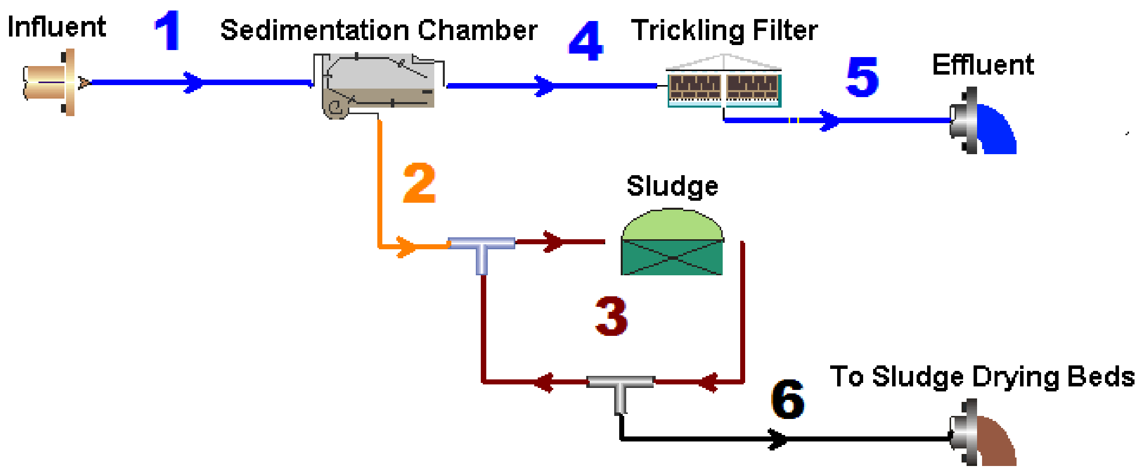


*Figure 2.2: The schematic as shown on the BioWin drawing board, indicating which step in the process each segment represents. Each line with arrow is an instantaneous transfer of flow from one process to the next.*

The Imhoff tank was modeled using an ideal primary settling tank, an anaerobic digester, a side stream mixer, and a splitter. The post-preliminary treatment influent flows into the sedimentation chamber. A small, highly concentrated flow goes down to the "sludge layer" which partially digests the solids. A small fraction was constantly wasted after the splitter to keep the model at steady state. The solids that were removed in this step represent solids floating up to the scum layer, which generally do not re-enter the system. However, the amount which floats up as scum would be smaller than the amount which was constantly wasted in BioWin. The anaerobic digester was set to mostly empty after a certain number of days, representing the periodic removal of sludge. More details on all parts of the schematic follow.

*Influent*

Many of the following influent values have been suggested for a small, mostly domestic municipal source (Noziac and Freese 2009) (Mogens 2008). The values for BOD and TSS were taken from data collected from the Leymebamba wastewater plant. BioWin uses carbonaceous BOD (cBOD) instead of BOD, so the cBOD was calculated based on ratio cBOD:BOD=0.766 (Muirhead, Farmer et al. 2006). Volatile suspended solids also had to be calculated and input into BioWin; this was done using a VSS:TSS ratio of 0.92 (Mogens 2008). All values input into the influent are noted in Table 2.1.

*Influent Flow*

The influent flow was estimated using a combination of sources. The flow was measured once in the Leymebamba wastewater plant on July 5, 2015 at 4 AM and 6 AM using a 20-L bucket and a stopwatch. It was known that the drinking water system in Leymebamba received 7-8 L/s from its source. A flow of 2.93 L/s was recorded at 4 AM. This seemed to be an unusually high flow at a time of night when flows should be at their lowest, leading one to assume that there was inflow and infiltration (I&I) from leaks into the collection system due to broken plumbing fixtures, etc. This theory was commonly speculated among the operators of the Leymebamba system. It was assumed that I&I occurred at all times; however, to be conservative, an estimated 1.5 L/s of I&I was used instead of the measured value. Every person was assumed to contribute 70 L/d, or about 1.62 L/s, of intentional sewage (Noziac and Freese 2009). Therefore, the flow to input into BioWin was calculated to be the sum of I&I and intentional sewage flows, which was 3.36 L/s or about 290 $m^3$/d.

*Grit Tank and Bar Screen*

The BioWin software does not include large solid inputs, such as trash and tree branches, but does have inert suspended solids (ISS). Grit tanks in BioWin only remove the ISS portion of the TSS.  A few simulations showed that the overall system was not very sensitive to the grit tanks and ISS removal. Therefore, the TSS levels in the influent were post-grit tank, assuming a 60% ISS removal.

*Natural Aeration with Weir*

After the grit tank in the Leymebamba plant, there is a Cipolletti weir that can be used for flow measurement as well as providing gravity aeration. Up to 2 kg $O_2$/KW h can be added to the wastewater using a weir with a 1-meter drop (Bagatur 2009). This value describes an amount of oxygen which can naturally enter water according to the power of the falling water. Calculations were performed to estimate the amount of oxygen that could potentially be added at the weir, and a conservative value of 2 mg/L of dissolved oxygen was used. This value was added in the influent element of BioWin.

*Sedimentation Chamber*

A settling tank was used in BioWin to represent the sedimentation chamber of the Imhoff tank. The volume was equal to that of the sedimentation chamber, as measured in the Leymebamba plant. It was set to constantly remove 70% of solids, as literature sources estimate that Imhoff tanks remove (Tilley, Ulrich et al. 2014). The solids sank down to the digestion chamber.

*Digestion Chamber*

An anaerobic digester was used in BioWin to represent the sludge layer of the Imhoff tank. The volume was set to one third of the volume of the actual digestion chamber in the Imhoff tank. This was to account for the lack of mechanical mixing resulting in a reduction of effective volume (Parkin and Owen 1986). The head space was considered to be the scum chambers of the Imhoff tank, but the head space value was found later to have no effect on the model anyway. Default values were used for the kinetic parameters.

*De-Sludging*

The sludge removal period is based on the temperature. Although the BioWin temperature was set to 15 degrees Celsius, which is closer to the annual average, the sludge was set to remove every 75 days as recommended for 10 degrees Celsius (Fondo Multilateral de Inversiones and AguaLimpia 2013). 75 days was thought to be more conservative. The outflow of the anaerobic digester was set to empty ¾ of its volume every 75 days because it is recommended to leave sludge in the Imhoff tank to keep the desired microorganisms active for the incoming sludge (Fondo Multilateral de Inversiones and AguaLimpia 2013).

*Trickling Filter*

The trickling filter in BioWin was set up in attempt to model the design in Leymebamba and Palmira. The main aspects included no recirculation, low aeration to simulate natural convection, and a rock media. Default values were used when applicable. Air velocities of 2 ft./min have been found under similar temperature differentials (Albertson and Okey 1988), which was calculated to be equal to 915 $m^3$/hr. of air flow to the filter.

| Parameter | Source | Value | Unit |
|---|---|---|---|
| Influent Flow | Measured + Lit | 290 | $m^3/d$ |
| BOD | Measured | 284 | mg/L |
| Carbonaceous BOD | Lit. Ratio cBOD:BOD=0.766 | 218 | mg/L |
| TSS | Measured | 132 | mg/L |
| VSS | Lit. Ratio VSS:TSS=0.92 | 122 | mg/L |
| Kjeldahl Nitrogen | Literature | 70 | mg/L |
| Phosphorus | Literature | 12 | mg/L |
| Nitrate | Literature | 0.2 | mg/L |
| pH | Literature | 7.5 | mg/L |
| Alkalinity | Literature | 3 | mg/L |
| Calcium | Default | 80 | mg/L |
| Magnesium | Default | 15 | mg/L |
| Dissolved Oxygen | Lit + Calcs | 2 | mg/L |
| Soluble Inert COD | Default | 0.05 | g COD/g total COD |
| Readily Biodegradable COD | Default | 0.16 | g COD/g total COD |
| Particulate Inert COD | Default | 0.13 | g COD/g total COD |
| ISS Removal in Grit Chamber | Assumption | 60 | % |
| Percent TSS Removal in Sedimentation Chamber | Literature | 70 | % |
| Underflow in Sedimentation Chamber | Assumption | 0.25 | % of influent flow |
| Kinetic Parameters for Anaerobic Digestion | Default | various | - |
| Air Flow to Trickling Filter | Lit + Calcs | 915 | cubic m/hour |
| Cycle Time for Splitter to Release Sludge | Maint. Recommendations | 75 | days |
| Temperature | Lit. Annual Avg. | 15 | deg. C |

*Table 2.1: Values used to create BioWin model and their sources*

### 2.3.3: Sensitivity Analysis

Once the model of the WWTP was created in BioWin, a sensitivity analysis was performed to find if the model was sensitive to change of certain parameters. Although there were many more possibilities from which to choose, a list of eight parameters was created, as tabulated in Table 2.2. These parameters were known to be uncertain and thought to be potentially impactful on the model. They were noticed and chosen during the model creation process. Three were operating parameters - underflow to sedimentation chamber, air flow to trickling filter, and percent removal in sedimentation chamber. Underflow to sedimentation chamber is the flow set in the ideal primary settling tank, as a percent of the influent flow which flows down to the anaerobic digester. Air flow to trickling filter is the air flow set to aerate the trickling filter, which was calculated by estimating the natural convection passing through the unit as a result of temperature differences. Percent removal in sedimentation chamber is the percent of suspended solids that the ideal primary settling tank is set to remove. The remaining five parameters investigated were wastewater influent characterization parameters - soluble inert COD fraction ($F_{us}$), readily biodegradable COD fraction ($F_{bs}$), particulate inert COD fraction ($F_{up}$), the VSS/TSS ratio, and the CBOD/BOD ratio. The COD fractions were simply edited in BioWin. The VSS/TSS ratio involved calculations as it was the post-preliminary VSS/TSS ratio. A 60% of inert suspended solids was always assumed to be removed in the grit chamber. The TSS concentration was set at 132 mg/L, as determined by averaging the measurements taken from the plant. Any changes for the VSS/TSS ratio only changed the VSS concentration and assumed a 60% removal of ISS. The cBOD/BOD ratio was necessary to estimate because the measurements taken at the plant in Peru were BOD5, and the BioWin software only uses carbonaceous BOD as an input, not accounting for the nitrogenous BOD. For the sensitivity analysis, the BOD concentration was at a constant 284 mg/L, which was the average of the measurements, and the cBOD value was varied in the different scenarios investigated.

| Parameter | Unit | Original Value |
|---|---|---|
| Underflow in Sedimentation Chamber | % of influent flow | 0.25 |
| Air Flow to Trickling Filter | cubic m/hour | 915 |
| Percent TSS Removal in Sedimentation Chamber | % | 70 |
| Soluble Inert COD | g COD/g total COD | 0.05 |
| Readily Biodegradable COD | g COD/g total COD | 0.16 |
| Particulate Inert COD | g COD/g total COD | 0.13 |
| VSS/TSS ratio | - | 0.924 |
| CBOD/BOD ratio | - | 0.766 |

*Table 2.2: Original values of parameters changed for sensitivity analysis.*

The sensitivity analysis was done by measuring the change in BOD and TSS removal as a result of changing the parameter values using BioWin. BOD and TSS removal were chosen as those parameters were the focus of the study as a whole. Absolute concentrations were not used because some of the parameters involved changing cBOD and TSS influent values, and measuring absolute effluent concentrations would have created skewed results. Steady state simulations were used, which produce time- and flow-weighted averages and find the solution to the system. First the removal for the original parameter values was calculated using the "properly maintained" base model. Then each parameter's value was changed by -10, -20, and -50%, running the simulation each time, and the BOD and TSS removal was recorded. The parameters were varied in a negative direction with respect to the baseline instead of a positive direction because some parameters were percentages which were too close to 100% to be increased in a positive direction and still represent a plausible value. After all the simulations had been run, the four most influential parameters were recorded to be used later.

### 2.3.4: Alternative Maintenance Scenarios

The alternative maintenance scenarios were changes made to the well-maintained BioWin model that demonstrated alternative maintenance practices to the WWTP as observed in Leymebamba, Peru. In the Palmira WWTP, the trickling filter was installed with the wrong type of rock, causing it to clog easily. Therefore, this scenario was modeled. In both WWTPs in the study, the sludge was regularly removed to the sludge drying beds. However, it was conceiveable that someday, especially after an election or change of authorities, one or both plants could be forgotten for a long time. The sludge would build up in the digestion chamber. This scenario was modeled as well. The BioWin software models conventional North American WWTPs that normally have automatic maintenance systems. Therefore, the model had to be programmed in unusual ways to simulate manual maintenance. The well-maintained model has settings that include solids removal of the anaerobic digester and a normally-functioning trickling filter. These settings were changed to simulate the following maintenance scenarios:

1. The digestion chamber of the Imhoff tank is never emptied of solids.

   In this scenario, the outflow pattern of the anaerobic digester and splitter that make up the digestion chamber section, instead of being set to empty ¾ of its volume every 75 days, was set to constantly waste only what is necessary to maintain steady-state conditions with respect to flow.

2. The trickling filter becomes clogged.

   In this scenario, the clogging of the trickling filter was simulated by reducing the area by 50%, from 36 $m^2$ to 18 $m^2$, thus reducing the effectiveness of the treatment.

Other alternate maintenance scenarios were seen during the observational period of the study, such as trash build-up in the bar screen or grit build-up in the grit tank. These scenarios were considered but ultimately could not be modeled using BioWin. For the scenarios chosen, the BOD and TSS removal was found using steady state simulations. After that, the models' sensitivity to the four most influential parameters from the first sensitivity analysis was tested. In this sensitivity analysis, the parameters' values were reduced by 20%, and the subsequent BOD and TSS removals were found using steady state simulations.

# 3: Qualitative Results and Discussion

## 3.1: Observation of Maintenance Practices

The WWTPs in Leymebamba and Palmira were observed and studied indirectly during the author's first 1.5 years living in the community, and then the plants were studied more purposefully beginning May 2015. The following section describes chronologically the observations of the plants and the maintenance performed on the plant, to the best of the author's knowledge, between May and November 2015.

The plant in Leymebamba, since its construction around 2008, had been in and out of operation. In 2014, it was observed to be functioning from August to December, after which the sewage was noted to have been diverted to the river. Discussions between the author and the local authorities began regarding the study in May 2015, and a preliminary visit was made with the MSD and operator. The plant at this time had no sewage entering it. The bar screens were full of rocks and sediment. The grit chamber had standing water. The Imhoff tank was partially empty. The trickling filter, drying beds, and general area were overgrown with plants. In June, a meeting was held with municipal authorities because the environmental prosecutor had visited and given the municipality a deadline to rehabilitate the plant. According to the environmental prosecutor, the consequences of not complying could be fines and/or criminal charges. Within days, the workers had cleaned up the plant, and it was operational again.

The following two months after the plant was rehabilitated, the maintenance was done consistently by Operator 1 and sometimes Operator 2. The operators were often observed to be going to the plant or commented that they were going there. They cleaned out the solids from the bar screens and before the grit chamber, multiple times a week. The long segments of the grit chamber were cleaned about once a month. The floating solids were taken out of the Imhoff tank. The sludge was purged into the drying bed initially upon rehabilitation and two months later as well. The sludge drying beds were also in good condition. The plants and dried sludge were removed from the beds and dumped next to the beds. The vegetation in the trickling filter had been removed, and the trickling filter seemed to be working correctly. After the first two months, the maintenance seemed to slow down. The bar screens and grit chamber were often found to be full of solids. The scum and floating solids in the Imhoff tank were not removed, forming a dense scum layer over the scum chambers by October, which is shown in Figure 3.1. Various dead animals could be found in the scum layer where they had presumably fallen in scavenging for food. The sludge was not purged again, but it had not yet reached the time for the next purging.

*Figure 3.1: Dense scum layer in Imhoff tank with dead animals*

The plant in Palmira had been running since its construction in 2013. The plant had been maintained by the former operator until the change of water committee in early 2014. During a first visit in November 2014, it appeared to be at least minimally maintained. The sludge had been recently purged to the drying beds and the solids in the bar screens and grit chamber had been cleaned. The trickling filter was clogged but not overflowing. When the discussion of the project began in May 2015, the author accompanied the vice president of the water committee to purge the sludge from the Imhoff tank, which he claimed to do every two months, although he was late on that purging. The dried sludge from the previous purging had not been removed either, which seemed to be a normal practice.

At that point, the plant had not been maintained in some time. Weeds had overgrown around the bar screen and grit chamber. The trickling filter was completely clogged and overflowing due to use of gravel instead of round rocks, as shown in Figure 3.2. He said that the man who has fields right next to the plant used to come to cut down the weeds. There was a lot of trash and green scum in the Imhoff tank. Weeds had grown in the sludge drying beds. After that visit in which he purged the sludge, cleaned some solids out of the bar screen, and cut the weeds down, no maintenance was done until August when the Leymebamba workers were sent to Palmira to clean the plant as demanded by the environmental prosecutor. They cleaned out the trash and solids from the bar screen, grit chamber, and Imhoff tank. The sludge was purged to the drying beds. The trickling filter was unclogged, and the water was passing through, although the gravel was not laid out evenly.

After that, the plant was not maintained until October, when the water committee decided to do a clean-up. The president of the water committee had an engineer from EMUSAP, Chachapoyas's water utility company, come and give them direction in the maintenance of the plant. This engineer encouraged them to clean out the bar screens, grit chamber, lower the gates of the grit chamber because they were too high, cut down the weeds and trees that had been planted right next to the bar screen/grit chamber, dig a hole for the trash from the plants, clean out the trash from the Imhoff tank, and dig out the dried sludge from the drying beds. He gave them recommendations for their trickling filter. The water committee took out over 20 large bags of dried sludge and sold them to a locals or the tree nursery for 2 soles per bag. After that, no more maintenance was performed during the study.

*Figure 3.2: Clogged trickling filter in Palmira*

The maintenance of the plants were scored for each month during the study period of May-November 2015. The tasks recommended for each treatment unit (Fondo Multilateral de Inversiones and AguaLimpia 2013) were graded with three maintenance levels: no maintenance, some maintenance, and proper maintenance, indicating how well or often they had been performed, on average. On charts, these maintenance levels are indicated with shaded blocks, as in Figures 3.3 for Leymebamba and 3.4 for Palmira. The maintenance can also be scored numerically with this grading scale: 0, 1, and 2 points correspond with no, some, and proper maintenance, respectively. Leymebamba received 35% of the total possible points, and Palmira received 22% of the total possible points. This demonstrates that Leymebamba's municipality performed more and/or more proper maintenance than Palmira's water committee, which is to be expected since Palmira is a smaller community with a voluntary water committee. Both administrations are performing maintenance, but there is much opportunity for improvement.

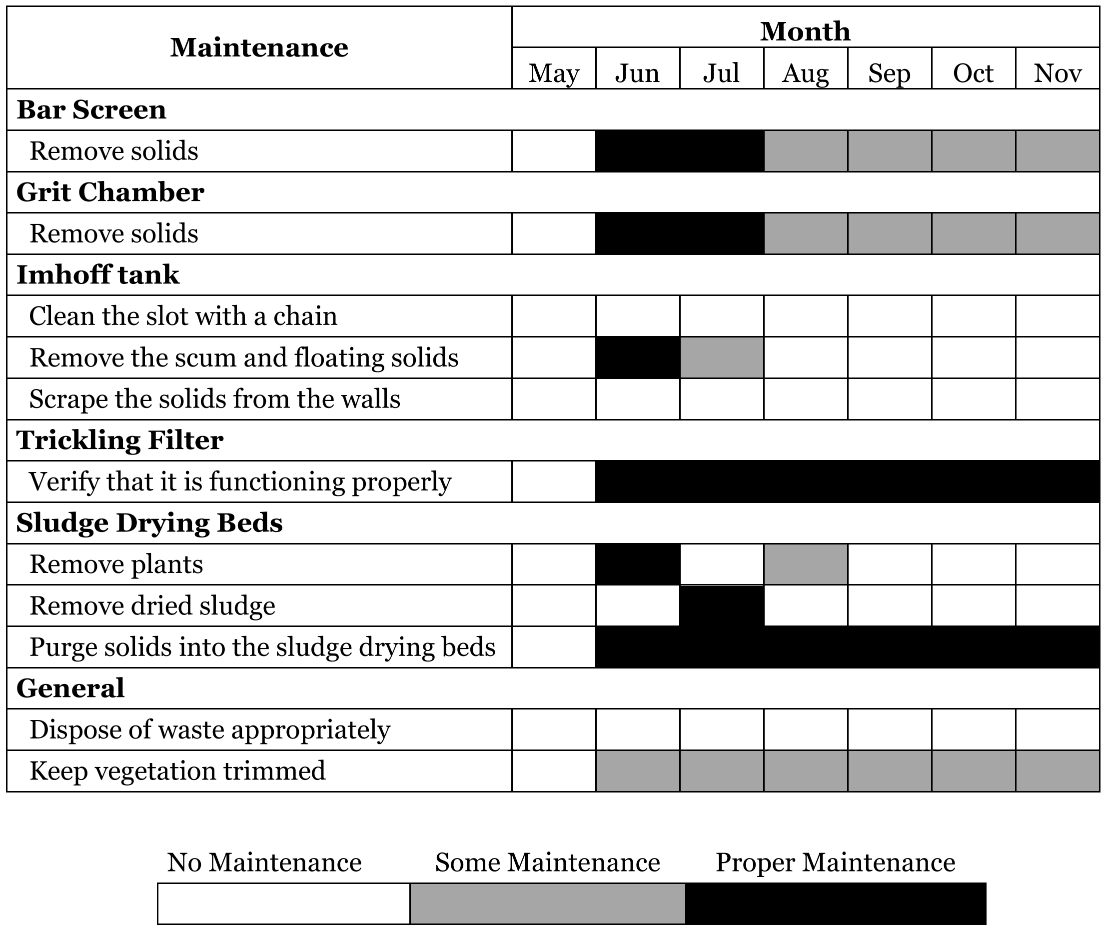


*Figure 3.3: Maintenance performed for specified tasks on Leymebamba WWTP between May and November 2015. Average amount of maintenance performed per month indicated by shading of cells.*

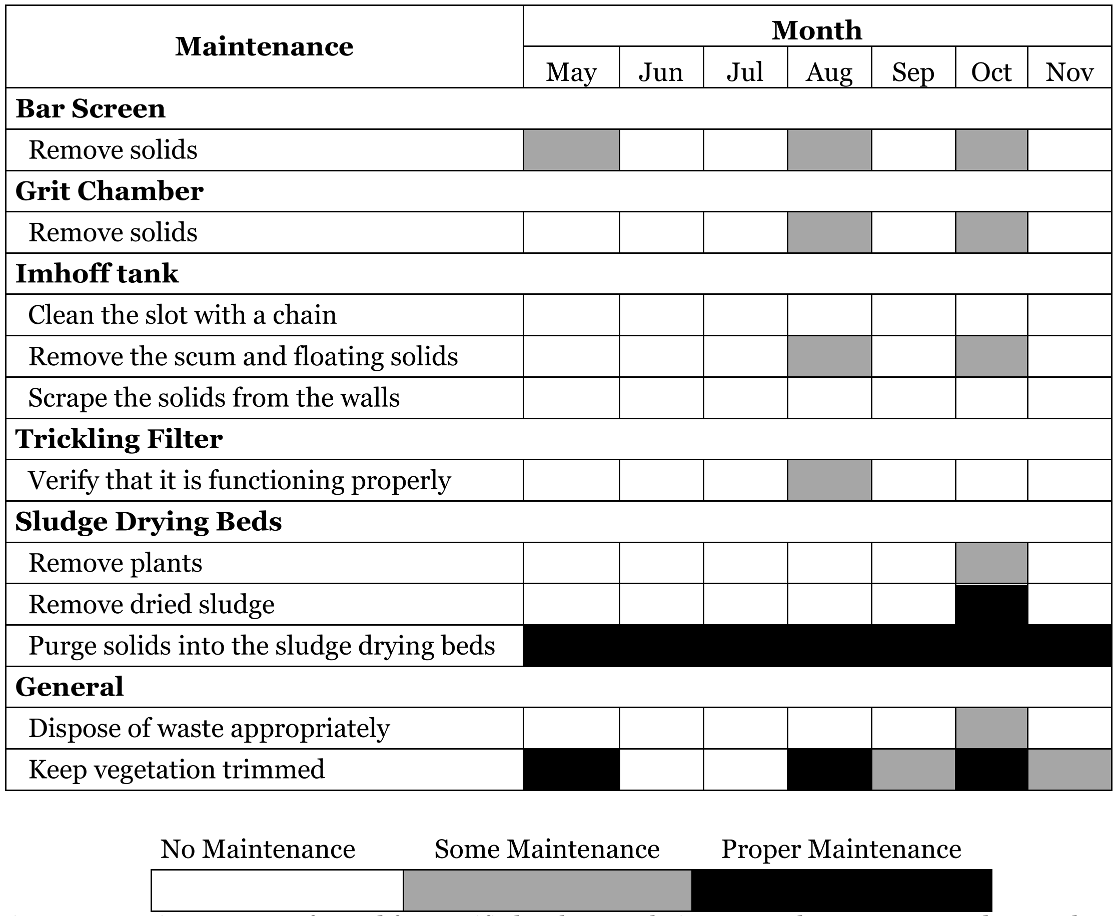


*Figure 3.4: Maintenance performed for specified tasks on Palmira WWTP between May and November 2015. Average amount of maintenance performed per month indicated by shading of cells.*

## 3.2: Motivations and Challenges

### 3.2.1: Motivations

As described in the previous segment, maintenance of the plants was performed by the workers and water committee members. One goal of the qualitative research was to find their motivations to do this laborious, and often unpleasant work.

*Supervision of Outside Authorities*

A strong motivator seemed to be the supervision of outside authorities. The environmental prosecutor visited in June, inspected the plants, told the Leymebamba municipal authorities that they were not in compliance with the law, and gave them a deadline to have the plants functional again or face fines. Several days later the authorities had met and rehabilitated the plant, sending photos as evidence. The speed and efficiency of their response showed that they were strongly motivated by the visit. In 2014, the previous year, the National Water Authority had visited for an inspection. The MSD in 2014 related the story, saying he was "nervous because he thought the municipality was going to be fined." They all had gone down to the see the plant, which was not functional, and the National Water Authority official told him that this was one of the "best-designed plants in Peru," and there was no reason the municipality should be unable to keep it in operation. After that, they began using it again, and it was "working perfectly" for months until the change in local government when it was forgotten again due to change of staff.

With the water committee in Palmira, the outside authorities were also a form of motivation. The environmental prosecutor gave them a visit and told them it was urgent that they clean up their plant. However, the Palmira water committee president and Leymebamba municipal authorities understood that Palmira would not be penalized for not complying; rather, the municipality of Leymebamba would be, so the water committee did not rush to clean it up. This is because Leymebamba is the district capital, and its municipality is responsible for smaller towns in the district. Therefore, at that moment, Leymebamba's municipality took the lead in cleaning up Palmira's plant. Even if they did not have the same sense of urgency from the environmental prosecutor, the water committee was generally aware that there were laws regarding the disposal and treatment of wastewater and potential fines for not adhering to those laws.

*Job Requirement for Operators*

In the case of the paid operators in Leymebamba, their primary motivation for performing maintenance was that their job required it. Operator 1 was the main water and sanitation worker. He mostly worked without direct supervision because he understood what needed to be done, especially in the case of the water system. Also, he seemed to like the work and get satisfaction from doing it well. He said, "It is important to enjoy the work; one cannot just dedicate themselves otherwise, because it is a lot of work." He often felt frustrated with other workers who would just try to get a task done as quickly as possible or only work hard in front of supervisors.

*Service to the Community*

The water committee in Palmira, who were working voluntarily, were motivated by their desire to serve the community. One member said, “In the assembly, the people chose me to serve on the water committee. I did not want to, but I enjoy serving the community.” There had been a water committee in place long enough (since 2002) that the community understood that it was an important organization that had the power to improve water access to the local people. However, that motivation mostly applied to drinking water. Wastewater treatment, being a new concept, did not receive priority, yet they understood that it was their responsibility to keep it maintained. Members from the water committee are shown working below in Figure 3.5.

*Figure 3.5: Water committee members visiting the Palmira WWTP*

*Reduction of Pollution to the River*

All participants interviewed in the study also agreed that the pollution of the river was an important problem, and that the WWTPs reduced that pollution. Operator 1 stated, “The purpose of the plant is to not pollute the river and to leave the water filtered and clean to go back in the river. There are people who live close to the river downstream; it is harmful to them. The trout are contaminated." The supervisor of the committee said, "Our plant is good because it improves the quality of water. The wastewater does not go directly into the river." Common problems cited from wastewater in the interviews were: diseases, harm to the fish/animals, and pollution of the river/environment.

### 3.2.2: Challenges

Although the authorities in Palmira and Leymebamba understood that maintaining the WWTPs was their responsibility, many challenges made it difficult to perform adequate maintenance. These challenges are categorized and scored for relative importance for both Leymebamba and Palmira in Figure 3.6. A challenge that is very important is one that significantly impeded the operation and maintenance of a WWTP. The same scoring rubric from the maintenance practice results section is used. One can see that more of the challenges were important for Palmira. These challenges are described in more detail below.

| Category | Challenge | Relative Importance | |
|---|---|---|---|
| | | Leymebamba | Palmira |
| Organizational | Lack of Knowledge and Training | Very Important | Very Important |
| | Lack of Coordination | Somewhat Important | Somewhat Important |
| | Change of Staff | Very Important | Somewhat Important |
| | Low Funds | Less Important | Very Important |
| | Lack of Operator | Less Important | Very Important |
| | Lack of Property Ownership | Somewhat Important | Less Important |
| Public Perception | Customer Problems | Less Important | Somewhat Important |
| | Low Awareness | Somewhat Important | Somewhat Important |
| Technical | Health Risks | Somewhat Important | Somewhat Important |
| | Poor Installations | Less Important | Very Important |
| | Deterioration | Somewhat Important | Somewhat Important |

Less Important | Somewhat Important | Very Important

*Figure 3.6: Challenges organized by category and relative importance*

*Lack of Knowledge and Training*

One of the primary challenges discussed with the participants was the lack of knowledge and training in the importance and operation of the WWTPs. Both communities had been visited exactly one time by technicians from the company that built their plant in which they indicated how to operate the plant. Not everyone involved with the plant currently had attended this session, and it had not given everyone who had attended a strong foundation. The operators and committee members who worked on the plant understood basic principles such as that the solids should be removed from the bar screen, the tank should be purged, the filter should not be clogged, etc. However, they did not understand theoretical ideas such as anaerobic digestion or trickling filter processes. One operator said he used bleach to clean the Imhoff tank, demonstrating that he did not understand that he would harm the bacteria working to digest the solids. A common need expressed by the participants was the need for training and better understanding of the plant. Operator 1 from Leymebamba said, “We have to start managing the plant more technically. Right now we know what to do from practice, so it would be very useful, since we are already involved, to learn more theory. Managing water systems is easy; I know a lot about water. But the wastewater treatment plant, not so much.” The research project included two training sessions to which most of the study participants came, as depicted in Figure 3.7. They seemed to have a better understanding of the plant afterwards. Also, the president of the water committee invited an engineer to Palmira to show them how to maintain the plant.


*Figure 3.7: Training session participant learning about different units and their function*

*Lack of Coordination*

The Leymebamba municipality and water committee also suffered from their lack of coordination within their organizations. In the municipality, the people who were most involved in water and sanitation were the operators, the MSD, the treasurer who accepted water bill payments, and the councilman who directed the workers. All of these people had many other responsibilities apart from working on water and sanitation, let alone the wastewater treatment plant. For example, the MSD also worked as the municipal social worker, office of the disabled, and sometimes as secretary. Operator 2 worked on street cleaning, maintenance, trash pick-up, construction, gardening in the plaza, and sometimes the water and wastewater systems. Operator 1 did mostly focus on water and sanitation work, but operating the drinking water system for a town of 2300 people required most of his time. Twice daily he had to adjust the water leaving the reservoir. Weekly he visited the intake up in the mountains - a full day trip. He operated the chlorinator, fixed any breaks in the network, and assisted with other nearby water systems as well. He was also sent to work on random assignments such as trash pick-up. Sometimes different people would tell him to do different tasks. He felt that if the roles were more defined, and if there was a person designated to work on the plant, then maintenance would be more consistent. Additionally, he had trouble coordinating purchases such as materials or transportation with his supervisors. Sometimes, if they took too long, he just bought them himself. Tools such as shovels were rarely provided for the workers; they had to bring them from their homes.

Lack of coordination in the water committee could also be noted in Palmira as well. Compared to the municipality, they had the advantage of a focus on water and sanitation services, but they had the disadvantage of being unpaid committee members with other jobs. It was difficult to get them to all meet together, and sometimes the members would show up very late to a meeting. The meetings themselves were well-organized, with agendas, and all the members had a voice in discussion topics. However, because it was difficult to arrange meetings with the whole committee, some matters were decided outside of meetings and not all members were informed. The president and vice president felt uncomfortable asking members to devote their time to the water committee, but the members wanted to be informed. One commented, "We do not have good coordination between members. Sometimes, some of us know about something, and others do not."

*Change of Staff*

Part of the reason behind their lack of organization and knowledge was that both the water committee and the municipality experience regular changes in administration; every two and four years, respectively. These changes are due to local elections, and historically the same groups are not usually re-elected. Sometimes workers continue working for the new administration, but many times they do not. Operator 2, but not Operator 1, had been working in 2014. In 2014, the plant in Leymebamba was functioning. At the beginning of 2015, a new municipality began their term. With all of the disorder, the plant was temporarily abandoned until June. The people who work on the administrative side mostly changed, but a few stayed because they had a type of tenure on the position. In Palmira, the elections happened every two years. The secretary commented, "It is hard because we do not have a lot of exact knowledge about the water system. This is because we are only here for two years. Just when we start learning and understanding things, the committee changes." Often records are lost, personnel are changed, and the former administration does not feel obligated to train the new one.

*Low Funds*

Another challenge facing these administrations is the low funds available or generated to cover the costs of the service. This was debilitating to the water committee in Palmira. Their only funds were those gained by users paying their water bill, at a price of 2 soles per month, which not all users always paid. The exchange rate for 1 sol was $0.31 on October 1, 2015 (Freecurrencyrates.com 2015). There were about 250 homes, and in an average month on their account sheets, they received 100-200 soles. They needed a full-time operator to be able to manage both the water and wastewater systems, which would cost at least 500 soles per month. This was clearly not feasible based on their income. The best solution would be to enforce the payments and charge more per month, yet they were afraid of outcry from the community if they attempted to do this. Also, they were required have approval from a majority of the users in order to raise the water bill, which the committee did not think would happen. The president said, "Some people in the community do not like it when we ask them to pay the water bill; they think it should be free because the last water system was built with the labor of the community, but the new system that was finished in 2013 was completely paid for and built by the regional government." In actuality the funds should not have been such an urgent problem because the committee had saved around 10,000 soles over the years, but most of it had been loaned to a committee member who had not paid it back. This was a source of internal conflict between the members as it prevented them from hiring workers and buying parts, nor did they want to hold a general assembly until the problem was resolved.

In the case of the municipality of Leymebamba, this was not as much of an issue. They were charging 5 soles per month. Also, they had been allotted a certain amount of their budget for running costs, which could include water and sanitation expenses. The MSD believed that only a small portion of the costs were covered by the water bill revenues. "We are practically donating the service," she said. Even though the municipality could afford to pay for workers and cover expenses, water and sanitation projects did not seem to be a priority. Much of their efforts were on new building projects, such as a municipal office and a stadium. Little effort was given to maintenance of existing infrastructure. There was still much more work to be done in water and sanitation that the current workforce would not be able to achieve while still handling their other responsibilities. Some workers were displeased with their salaries, and felt that they were not being well compensated for their work. One mentioned that he was being paid the same as he would make working in the fields, yet he was technically trained and held much greater responsibility (to the health of Leymebamba) than a field worker. Also, he was putting his health at risk by disinfecting the water tanks with chlorine and working on the WWTP.

*Lack of Operator*

Palmira's most significant inhibitor to proper WWTP maintenance was the lack of a regular operator. As previously mentioned, they were not able to afford the salary for a full-time operator. In July, the committee contracted a previous operator to be paid by the day. However, it seemed that they only utilized his services in times of emergency in order to save money. Once, this worker finished his work at 3 PM instead of 5 PM, and the president wanted to pay him less for not completing the whole day. The worker felt insulted. When possible, they asked members of the water committee to do any necessary work, likely being paid minimally. This was the arrangement when they cleaned up the plant in October. However, all the members understood that it would be ideal to have a full-time operator, especially one with experience.

*Lack of Property Ownership*

Lack of ownership of the WWTP property was another problem that impeded Leymebamba's administration. They had not purchased the whole property where the plant was located; rather, they purchased the exact land needed to construct the units. This was a problem for two reasons: they did not have permission to dig holes to properly dispose the waste removed from the plant, and they did not have a suitable entryway to the plant. Instead of burying the waste, they simply threw it to the side. The owner was not pleased about it, and it attracted flies and other disease vectors. The owner did not seem interested in selling more land for the disposal of sewage waste either. Two paths could be taken to the plant: one which was locked with a gate and another which was down a muddy, steep hill next to a spiteful relative of the operator who had been known to throw rocks at him as he passed. The operator had to hack a new path around the locked gate to gain access. The owner of the land did not seem to want to provide them keys to the gate.

*Customer Problems*

The water committee in Palmira experienced a variety of frustrations involving their users. Almost all water committee members commented that about half the community was unsatisfied with their service. This was mostly due to occasional drinking water-related issues such as loss of water without notice, low pressure, and visibly dirty water. The users would call or find the committee members to complain. One member was very frustrated with this. He recounted a time when a man's daughter stepped on and broke a pipe in an uncovered inspection box, and then the man went to him and said, "You are in charge; hurry up and fix it!" He wanted to resign, but the other members would not allow it. Another member commented in reference to this event, "You know if you join a committee like this, the people are not going to thank you; they will just be angry with you. We all knew that coming into this. I agreed to be a part of the committee, and I am going to do it." Yet to many of the members, it was demoralizing to not receive appreciation from the community for their voluntary service.

*Low Awareness*

One reason that the community may not have been very appreciative was they were generally uninformed about water and sanitation issues, especially the WWTP. The committee members in Palmira said that most people did not know anything about it, except for perhaps where the plant was. The same was true in Leymebamba. One difference between the plants was that the Leymebamba plant was visible from the main road. One could observe, if they were looking, whether or not the sewage was flowing into the plant or being diverted into the river. Perhaps for that reason, there was some commentary about the plant not being designed well because for some years it had not been used; whereas, in Palmira, one would have to actually visit the plant to be able to see it. The MSD said about the Leymebamba plant, "The people do not have an opinion about the plant, because they do not know anything about it. And if they have an opinion, it is totally unfounded."

The lack of awareness about the plant resulted in greater problems than local gossip. Of those who maintained the plant, one of their major complaints was that users put inappropriate, damaging materials into the sewage system. If one visited a WWTP, they would find all types of trash - bags, bottles, wrappers, diapers, etc. They would find dirt, sand, and rocks that people wash down their drains in their patios. They would even find entire animals - chickens, pigs, dogs, or birds; although, some of those may have fallen in at the actual plant. Operator 1 and the MSD believed that this happened because people did not understand that the sewage system could be clogged, and they felt that the solution was to educate the community. “We have to teach how to use the sewage system in the elementary and high schools, so that the children can transmit these ideas to their parents,” said Operator 1. They had similar ideas in Palmira. The president of the water committee said, “We need sessions to teach the community about not throwing trash in the sewage system.” After that the community would theoretically treat their system better, and the maintenance would be easier.

*Health Risks*

Apart from the troubles that the community caused, the work itself was not easy nor enjoyable. It generally required interaction with human waste, which is not only unpleasant to see and smell but also is heavily concentrated with pathogens. An operator at Leymebamba said, “It is difficult work. It makes you nauseous and takes away your appetite. Our supervisors think we do not have stomachs like everyone else.” Another operator said, “We have to change boots all the time because the water enters, and the smell does not leave.” They usually worked in old clothes, tall rubber boots, and long heavy-duty rubber gloves. The participants, especially those who actually had worked on the plant, often mentioned that they would feel safer wearing personal protective equipment such as eye protection, mouth and nose masks, coveralls, and stronger boots. Operator 1 commented, “We need uniforms. We are unprotected and it is a health risk. We want to work, but we want to live one more day.” The people who were more administrative also were in favor of protective gear, once they learned of their working conditions.

Some people, interestingly, did not seem deterred by raw sewage. While visiting the WWTP in Palmira, one member saw fruit growing wild next to the Imhoff tank. He immediately began offering the fruit to others and eating it himself, to the horror of those around him. Another story was recounted once about a worker in a nearby community who would touch or scrape out wastewater solids with his bare hands and afterwards use them to chew coca leaves. Similarly, Operator 1 said that some people like to fish trout right downstream of the sewage outflow because they say it is more delicious there. The operator, however, also said that many people are wary of fish from there because they might have disease. This shows that although some people were not concerned with the hazards of wastewater, many were.

*Poor Installations*

The Palmira water committee struggled with the poorly built water and wastewater systems that an engineering company had left them. The systems were completed in 2013 and by 2015 already had serious problems with the intake, connections, and trickling filter. The company had used old, poor-quality valves and tubes which had broken many times and needed replacing soon after installation. In the case of the trickling filter, they hired a local man to finish building it. The man did not know that he should put round stones; he put gravel instead, and the trickling filter became clogged and overflowing within a year. According to the president, the company was supposed to help with any problems for seven years, but because it was never officially handed over to the Palmira water committee, the municipality was responsible for communicating with the company. Needless to say, there were no communications, and the water committee was paying to fix the company's poor-quality work.

*Deterioration*

Because they had not been operated and maintained as designed, some parts of the Leymebamba and even Palmira WWTP were beginning to deteriorate, limiting the plants' abilities to treat effectively. In Leymebamba, the gates for the grit chamber had rusted and were unable to move. There was a leak from the pipe which directed sewage to the Imhoff tank, leaving the area muddy. In Palmira, one of the pipes that purged sludge barely worked, which caused the sludge to flow out unevenly. The administrations recognized the need to perform better maintenance, and they understood that better maintenance would prevent deterioration. The MSD said, "There needs to be more prevention of problems instead of just reaction to problems."

## 3.3: Discussion

There were many motivations and challenges of management of the wastewater systems in Leymebamba and Palmira, and many were similar to those faced in other studies. Some of the main factors cited in past studies were: appropriateness of technology, quality of construction, maintenance, community awareness of WWTP, and accountability (Murray and Drechsel 2011) (Mikelonis, Herrera et al. 2010) (Massoud, Tareen et al. 2010) (Haase 2010) (Cairns 2014) (Ratner and Rivera Gutiérrez 2004) (Fuchs and Mihelcic 2011). The technology seemed to be appropriate in this case – it provided a simple and economical method to treat small wastewater flows. The construction quality was poor in Palmira and seemed to be an impediment to the water committee's smooth functionality. In Leymebamba this was not mentioned as an issue. Regular maintenance was a focus of this study and seemed to especially be a challenge for Palmira, who did not have a permanent operator. In both communities, certain maintenance tasks were not done simply because the operators were not trained to do them. The community's awareness of the WWTP was an issue that was important to the authorities and plant operators, especially because the townspeople put trash and solids down the pipes that would clog the system. Finally, accountability proved to be essential since Leymebamba's municipality was strongly motivated to work on the WWTPs after the environmental prosecutor's visit. Therefore, all of these factors were relevant in this case study, and they should continue to be a focus in future rural WWTP design, construction, and maintenance.

One interesting facet of this study was the comparison of the two different styles of administration – the municipality in Leymebamba and the water committee in Palmira. The municipality seemed more equipped to handle the challenges of wastewater treatment maintenance because they had funds and a permanent operator. Palmira did not have many funds during the study, but even with their lack of resources, the Palmira water committee was been able to keep their plant functioning. Both types of administration could potentially do a good job if they were well organized. Looking at motivations, it was observed that Leymebamba's municipality was most motivated by the supervision of outside authorities and Palmira's water committee was most motivated by serving their community. The motivation to serve the community did not align with maintenance of the WWTP in this case because the community at large was unaware or indifferent to wastewater treatment issues. The outside authorities, on the other hand, were very concerned about the state of the WWTPs and were a much stronger motivation.

There were many challenges which hindered proper maintenance. It was observed that different maintenance tasks were not performed for different reasons. Table 3.1 below describes the primary reasons that individual maintenance tasks were not performed, based on observations and conversations of the Palmira and Leymebamba WWTP and administrations. For example, there were some tasks that the operators did not perform because they simply did not have the training or tools to do them, such as cleaning the slot of the Imhoff tank with a chain. Other tasks, such as removing the solids from the bar screen, were not performed in Palmira because, although they were aware that the task was important, they did not have a regular operator to do it.

| Maintenance | Primary Reason(s) for Not Completing Task |
|---|---|
| **Bar Screen/Grit Chamber** | |
| Remove solids | Lack of operator |
| **Imhoff tank** | |
| Clean the slot with a chain | Lack of training and tools |
| Remove the scum and floating solids | Lack of operator and training |
| Scrape the solids from the walls | Lack of training and tools |
| **Trickling Filter** | |
| Verify that it is functioning properly | Poor installation |
| **Sludge Drying Beds** | |
| Remove plants | Lack of training |
| Remove dried sludge | Lack of operator and training |
| Purge solids into the sludge drying beds | Change of staff |
| **General Site** | |
| Dispose of waste appropriately | Lack of training |
| Keep vegetation trimmed | Lack of operator |

*Table 3.1: Primary reasons found that certain maintenance tasks were not performed*

# 4: Quantitative Results and Discussion

## 4.1: Wastewater Measurements

The results of the laboratory tests of the influent and effluent wastewater show that the BOD and TSS values were variable for all five tests, with relatively high standard deviations, as shown in Figure 4.1 and 4.2. The influent values in particular could have had large standard deviations because the plant is smaller and more impacted by incoming flows and fluctuations. The TSS measurements on August 17, 2015 were 121 mg/L influent TSS and 250 mg/L effluent TSS. These results were not included in the charts or further calculations because their reliability was doubted. Average removals of BOD and TSS were calculated using influent and effluent data. Calculating removal assumes that the system was at steady state, but because of the infrequency of the measurements, it is unknown whether the system was at steady state or not. Therefore, effluent measurements may not related to the influent concentrations and may instead represent conditions at a different time. With this warning at mind, the average removals calculated from these data points with the assumption of steady state conditions estimate that the plants were performing well on average, with 49.5% BOD removal and 53.8% TSS removal at the Leymebamba plant and 48.3% BOD removal and 71.2% TSS removal at the Palmira plant. These results are shown in Figures 4.1 and 4.2, and the averages and standard deviation for each sample point is shown in Table 4.1. Regarding BOD removal, the WWTP was estimated to perform better than most of the plants in previous literature, and with respect to TSS removal, the plant performed similarly. However, further testing would be needed to more accurately describe the treatment that these WWTPs provide.

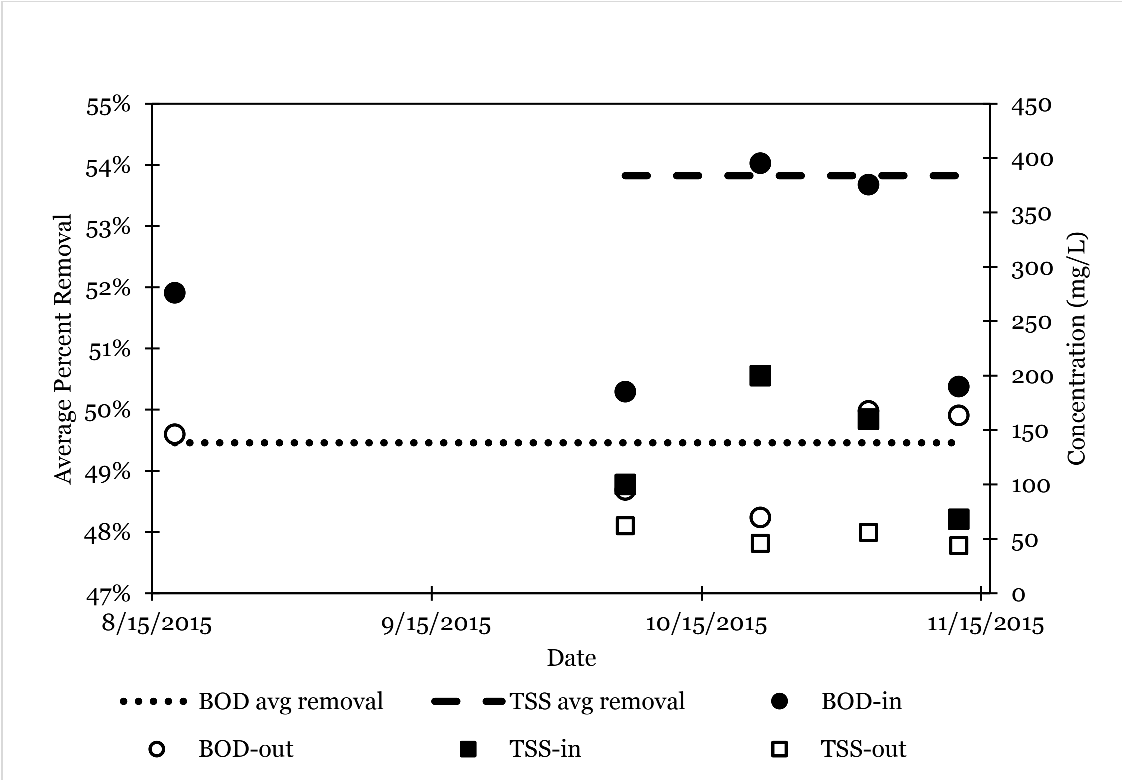


*Figure 4.1: Laboratory test results of samples taken from Leymebamba WWTP. The points indicate all influent and effluent measurements, and the average removal lines are calculations of BOD and TSS removal using the influent and effluent test points assuming steady state conditions in the wastewater influent. The removal was averaged for all testing days. The TSS measurements on 8/17/2015 were reported above but not used in the analysis.*

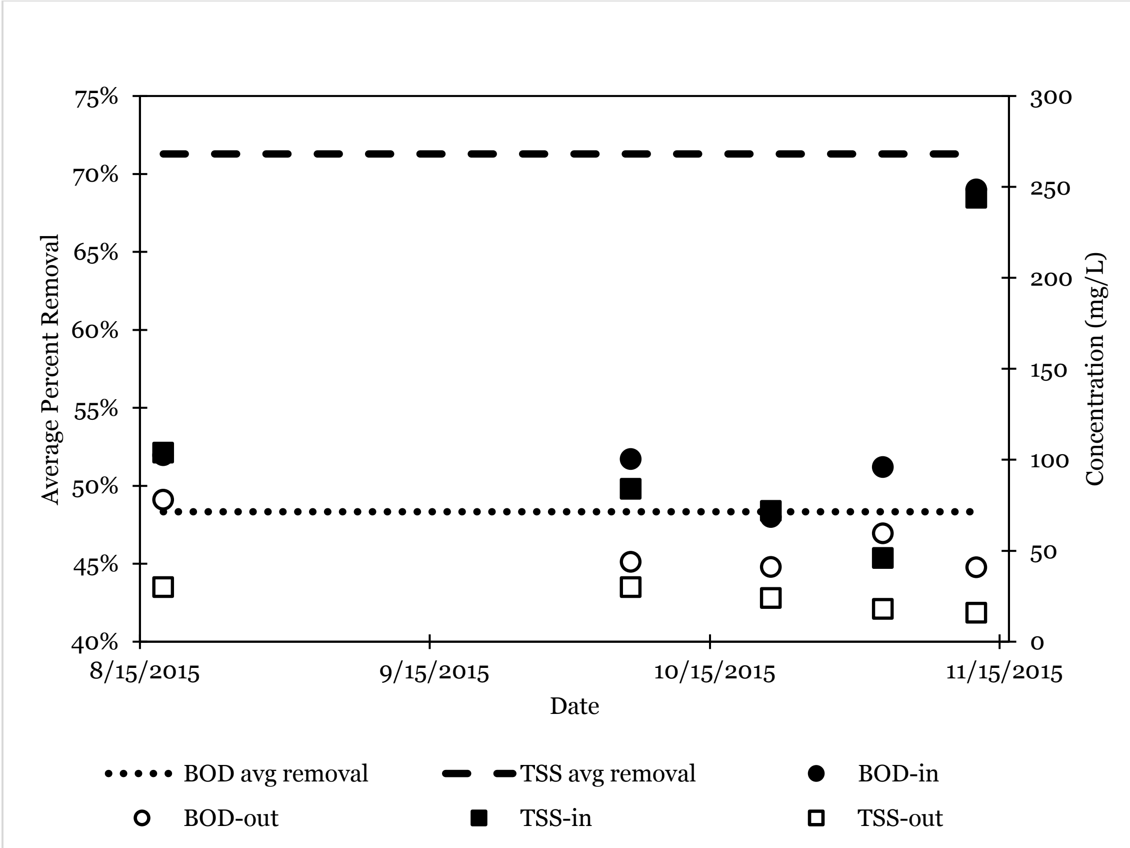


*Figure 4.2: Laboratory test results of samples taken from Palmira WWTP. The points indicate all influent and effluent measurements, and the average removal lines are calculations of BOD and TSS removal using the influent and effluent test points assuming steady state conditions in the wastewater influent. The removal was averaged for all testing days.*

| Town | Parameter | Average Value (mg/L) | Standard Deviation (mg/L) |
|---|---|---|---|
| Leymebamba | BOD-in | 285 | 99 |
| | BOD-out | 129 | 44 |
| | TSS-in | 132 | 59 |
| | TSS-out | 52 | 8 |
| Palmira | BOD-in | 123 | 71 |
| | BOD-out | 53 | 16 |
| | TSS-in | 110 | 78 |
| | TSS-out | 24 | 7 |

*Table 4.1: Average values and standard deviations of the laboratory results.*

## 4.2: BioWin Modeling Results

### 4.2.1: Properly Maintained BioWin Base Model

The BioWin base model designed assuming proper maintenance practices was able to achieve 24.8% BOD removal and 66.5% TSS removal. This fell within the range of estimated removals for an Imhoff tank system. Only the TSS removal fell within the standard deviation of the calculated average removals in the Leymebamba WWTP. The BOD removal predicted by BioWin was slightly outside of the standard deviation of average plant measurements, as shown in Table 4.2. However, there were only five samples taken of influent and effluent wastewater, so it is unclear how accurate the measurements were in describing the contaminant removals, and again, it is unknown if the system was at steady state during the sampling. Also, it is possible that there were processes going on in the actual WWTP that were unusual or outside of BioWin's ability to simulate. Only BOD and TSS were measured, and they were only measured at the entry and exit of the plant. For greater understanding, more frequent tests should be done at different points in the plant, and other parameters should be measured to obtain a more complete picture of the processes occurring and the characterization of the wastewater.

| **Avg Removal from Plant Msmts** | | **BioWin Model Removal** | |
|---|---|---|---|
| BOD | TSS | BOD | TSS |
| 49.5±24.4% | 54.8±20.5% | 24.8% | 66.5% |

*Table 4.2: BOD and TSS removal averages in the Leymebamba WWTP and BioWin model. The average removal in the Leymebamba WWTP (left side of table) was calculated using influent and effluent measurements taken. Standard deviation is shown.*

### 4.2.2: Sensitivity Analysis

A sensitivity analysis was performed on eight parameters in the model by changing their original values -10, -20, and -50%. Of those eight parameters, the four most sensitive parameters were, in order of sensitivity, cBOD/BOD ratio, VSS/TSS ratio, percent SS removal, and particulate inert COD fraction. The other parameters were found to have very little to no impact on the model outputs. The graph is shown in Figure 4.3 below.

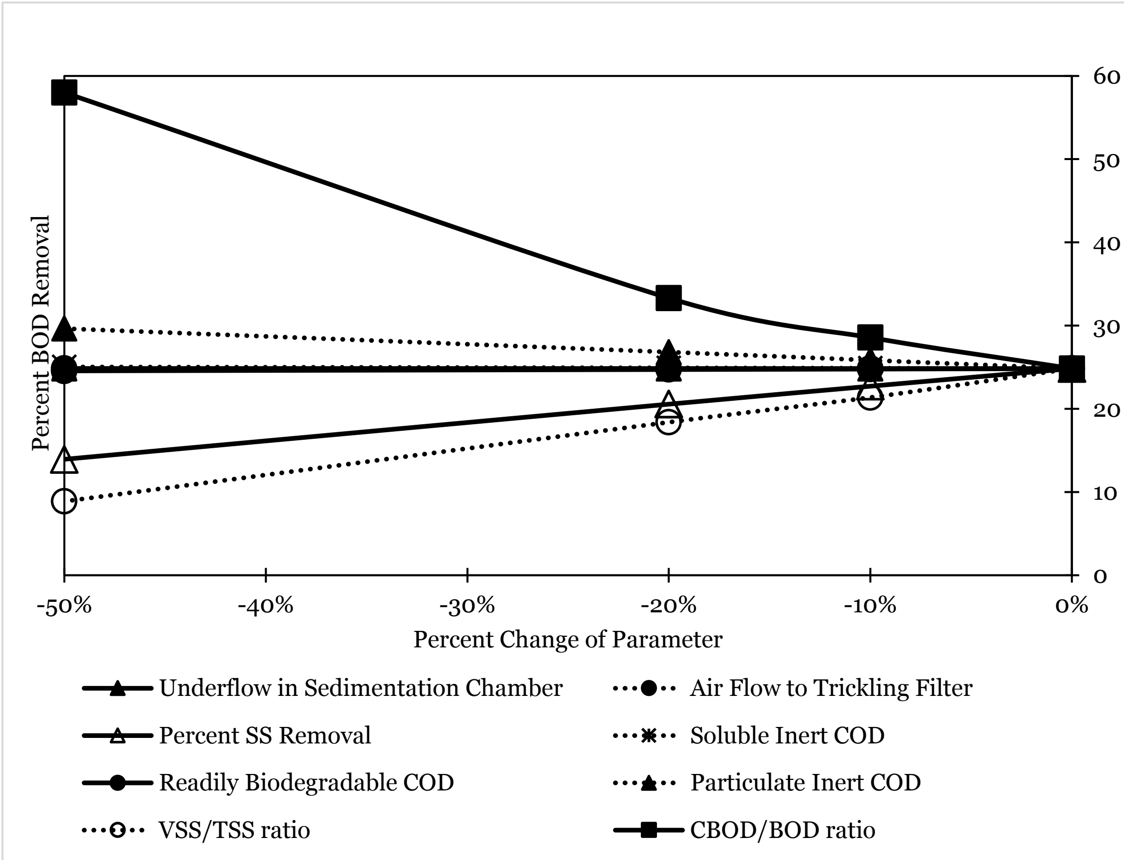


*Figure 4.3: Sensitivity analysis of parameters on BOD removal in BioWin model.*

Of those same eight parameters, the three most sensitive parameters with TSS removal were, in order of sensitivity, percent SS removal, VSS/TSS ratio, and cBOD/BOD ratio. The other parameters were found to have very little to no impact on the model outputs. The graph is shown in Figure 4.4 below.

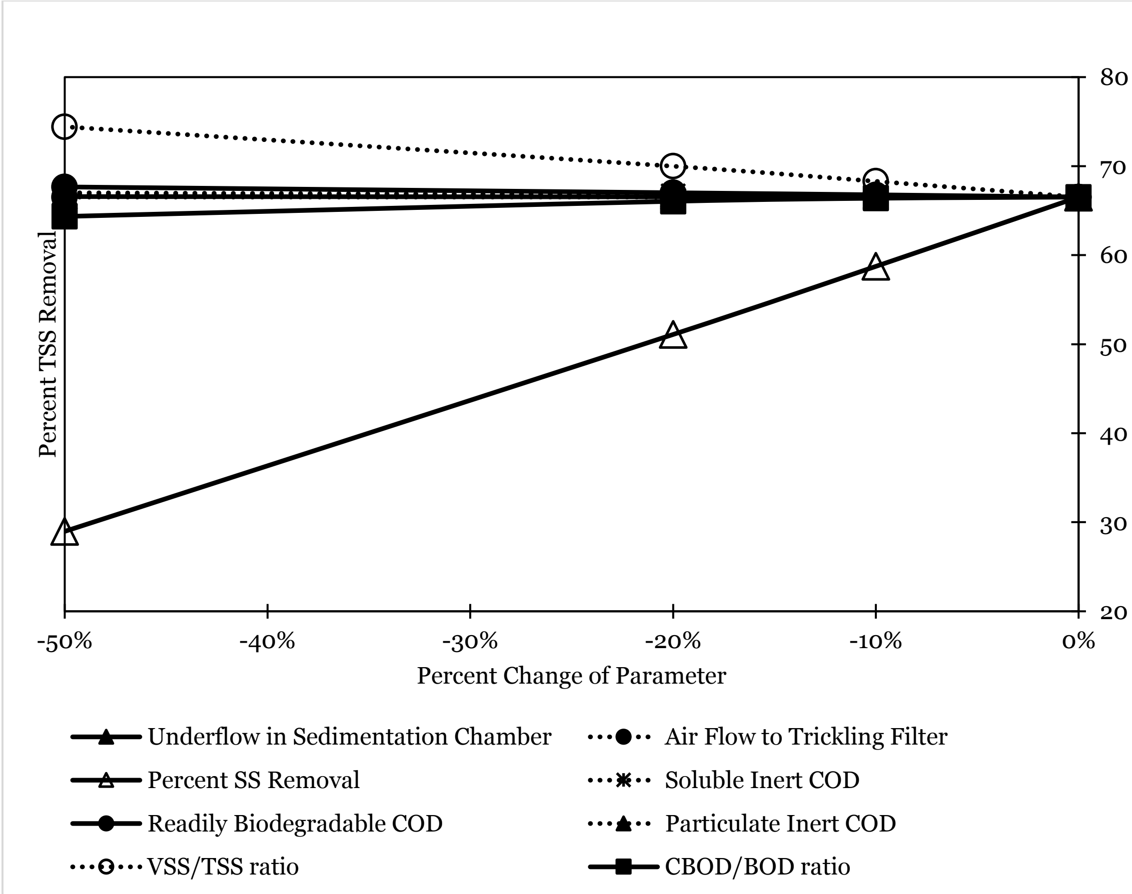


*Figure 4.4: Sensitivity analysis of parameters on TSS removal in BioWin model.*

## 4.5: Alternative Maintenance Scenario BioWin Models

After the base model was created to show proper maintenance, two alternative models were developed to show different maintenance practices. In Scenario 1, the solids were never emptied from the Imhoff tank. In Scenario 2, the trickling filter was clogged.

The Scenario 1 model produced outputs identical to the base model's outputs, whereas the results for the Scenario 2 model were very similar to that of the base model. Table 4.3 displays these removals. The results for Scenario 1 were reasonable because Imhoff tanks are designed to handle low to no maintenance, so it made sense that not performing maintenance would have little effect, at least for some time. At a certain point, the solids would have built up to the level of the slot where the solids pass through to settle in the lower chamber. At this point, the Imhoff tank would be functioning as an undersized septic tank, and some settled solids may be re-suspended by the higher velocities in that upper chamber. This scenario was not modeled, but it should be examined in future studies. The results for Scenario 2 were reasonable because the trickling filter was already overloaded in the base model; while experimenting in BioWin, it was found that the BOD removal of the trickling filter increased as the surface area increased. With the trickling filter and flow values as set in BioWin, the only about 5 mg/L of BOD was removed by the trickling filter in the base model. Overloading even more by reducing the surface area did not have much effect. The TSS removal increased as a result of clogging because the trickling filter causes sloughing of solids when it is working properly which increases the concentration of TSS. With the trickling filter less effective, the TSS is not being sloughed into the effluent as much. It also should be mentioned that for the measurements taken, no obvious trends were found correlating maintenance practices to plant performance. For example, the trickling filter in Palmira performed similarly when it was clogged and when it was not clogged. This is not conclusive because few data points were taken and should be explored further.

| **Parameter Removal** | **Base Model** | **Scenario 1** | **Scenario 2** |
|---|---|---|---|
| BOD (%) | 24.8 | 24.8 | 24.2 |
| TSS (%) | 66.5 | 66.5 | 69.4 |

*Table 4.3: BOD and TSS percent removals for each model.*

These results showed that the performance of the WWTPs as predicted by the model was not significantly impacted by the different maintenance scenarios. However, other negative effects of not performing regular maintenance such as odor, clogging, deterioration, and vector breeding would still be occurring. These effects were not examined as they were outside the scope of BioWin's capability, yet they should not be forgotten.

A sensitivity analysis of the alternative scenarios was performed, testing the models by changing the four most sensitive inputs as seen in the earlier sensitivity analysis. Those inputs were particulate inert COD fraction, VSS/TSS ratio, percent SS removal, and cBOD/BOD ratio. The Scenario 1 model results were identical to the Base Model results, and the Scenario 2 model varied only slightly. Results are shown in Figures 4.5 and 4.6. This demonstrates again that the effects of maintenance were limited, even when changing sensitive parameters.

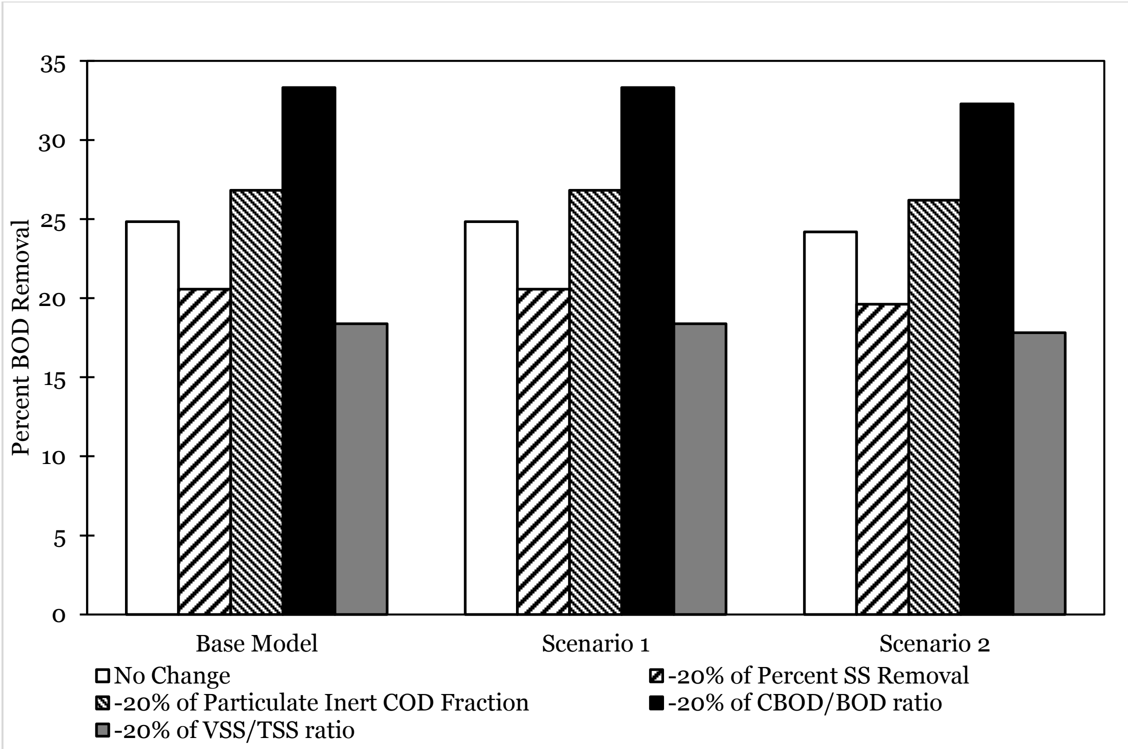


*Figure 4.5: BOD removals in each scenario with 20% parameter decrease.*

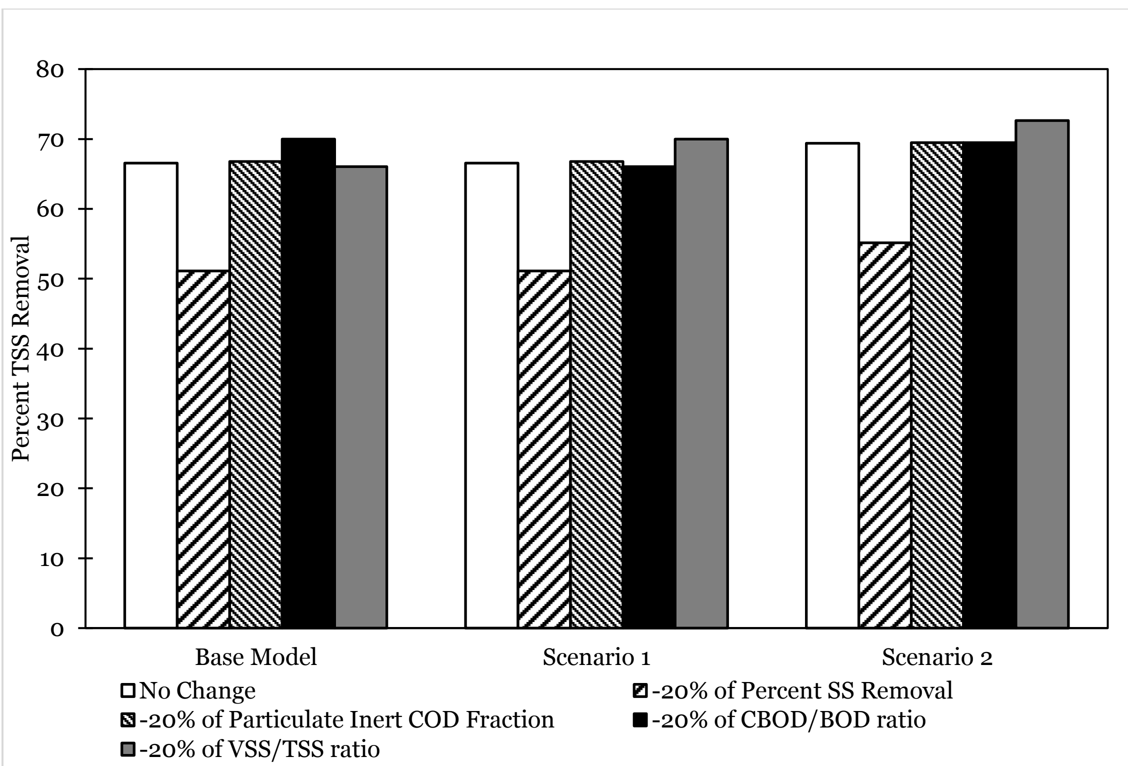


*Figure 4.6: TSS removals in each scenario with 20% parameter decrease.*

# 5: Conclusions and Recommendations

This study examined maintenance of two small WWTPs in Leymebamba, Peru. Challenges and motivations related to management and maintenance were examined, the performance of the WWTPs was tested, and then the effects of maintenance were simulated in a BioWin model. A key motivating factor was found to be the supervision of outside authorities, and important challenges were the lack of an operator and lack of training. With the measurements, it was estimated that the wastewater treatment was relatively effective in both WWTPs. The BioWin model performed over one standard deviation below the mean with respect to the average BOD removal, and it performed within one standard deviation of the mean with respect to the average TSS removal. In the alternative maintenance scenarios, it was predicted that the BOD and TSS removal would not be significantly impacted by not emptying the Imhoff tank or the clogged trickling filter.

This study found that maintenance did not significantly impact performance of the BioWin model WWTP, but that does not mean that maintenance is not important to the functionality of the plant. WWTPs that are heavily loaded with large solids will clog, overflow, and/or attract animals and disease vectors. BioWin does not currently have the capabilities to explore those scenarios. Another idea to consider is that most technologies have tradeoffs. If there is a greater requirement for maintenance then the treatment may likely be more effective; however, the likelihood will be greater that it will be too much work and be abandoned. In communities like Leymebamba and Palmira, where there are low resources and awareness about wastewater treatment, it is ideal to have a WWTP that can handle periods of low to no maintenance. As the communities become more organized and receive more outside support and training, they could eventually take on a more complex treatment technology. As of now, their accomplishment in managing the WWTPs is commendable, and there is optimism that their work will improve as they grow to understand its importance.

Recommendations for the operators and administrators of the WWTPs in Leymebamba and other similar communities would be to improve the maintenance and management of the plant in a way that is sustainable and consistent. Educating their communities and seeking advice and training from experts would be very beneficial. They should remember to consider wastewater costs when deciding how much to charge customers for water and sewer services. Development workers should keep the lessons from this and similar studies in mind when attempting to help communities improve their wastewater management. In particular, governments should put more resources into training and supervising small communities with wastewater treatment plants.

Contributions of this study were the examination of WWTP maintenance from both cultural and technical angles and the creation of a BioWin model for an Imhoff tank. Future studies could include more in-depth research into the relationship between maintenance and performance. More measurements would be needed to validate findings from this study. The BioWin model could be more accurately calibrated with these measurements to provide more useful results. Action research would be useful to find what motivates wastewater management administrations in an empirical manner. A study to compare wastewater treatment and management in various towns or regions of the world would shine light on regional or cultural challenges. This has only been a study of one community out of many around the world, improving its wastewater management and contributing to the betterment of human and ecosystem health.

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# 7: Appendices

## Appendix A: IRB Approval

**Michigan Tech**

Michigan Technological University

Office of Compliance,
Integrity, and Safety
302 Lakeshore Center
1400 Townsend Drive
Houghton, MI 49931
906.487.2902

MEMO

| | |
|---|---|
| DATE: | July 13, 2015 |
| TO: | Alex Mayer, PhD, Civil |
| FROM: | Cheryl A Gherna, CIP, Coordinator Regulatory Review Boards Cheryl A Gherna |
| RE: | M1351, [709761-1] |
| TITLE: | Operation and Maintenance of Wastewater Treatment in Amazonas, Peru |
| SUBMISSION TYPE: | New Project |
| STATUS: | **APPROVED, Exempt Status** |

Thank you for your submission of materials for this research study. Your application to use human subjects in research or classroom situations has been reviewed and determined to have an Exempt status.

This approval is based on no greater than minimal risk to research participants. All research must be conducted in accordance with the approved submission; if ANY changes are made in the protocol or conditions set forth in the application, the principal investigator must obtain a separate approval before the changes are implemented, other than to avoid any immediate harm to the subject.

When a research project is determined by the Office of Compliance, Integrity, and Safety (CIS) to meet the criteria for an Exempt status, it means that it is exempt from annual continuing review by the Institutional Review Board (IRB). The investigator, however is required to report to the IRB ANY changes, revisions, or modifications in the research activity including personnel changes. ANY changes made may cause the research status to change from Exempt to Expedited or Full Review and must be determined and documented by the CIS Office.

**All Unanticipated Problems / Serious Adverse Events to participants or other parties affected by the research** must be reported to this office within two days of the event occurrence. All instances of non-compliance or complaints regarding this study must be reported to this office in a timely manner. Please use the INSTRUCTIONS and FORM: Unanticipated Problem / Serious Adverse Event Form found both on our web site and the IRBNet Library.

**This approval applies only for this project, and only under the conditions and procedures described in the application.** If/when changes become necessary but are not limited to: changes in protocol, personnel, study location, participant recruitment, etc., as set forth in this approval, you must follow the INSTRUCTIONS and submit the FORM for Change Request during approval found in the IRBNet Library. **You must receive notification of approval PRIOR to implementing the change(s).**

If you have any questions, please contact the Compliance, Integrity, and Safety Office at 906.487.2902 or send your message via email through IRBNet using the Send Project Mail feature.

# Appendix B: Interview Questions in English

**Leymebamba:**

**Questions to Water Administration**
**Demographics**
What is your name?
What is your position?
What is your age?
What is your education level?
What is your monthly salary?
**Job Opinions**
What are the primary responsibilities of your job?
What are your primary responsibilities in water and sanitation?
Did you have prior experience working in water and sanitation before obtaining this job?
Have you received training to work in this position?
How is the municipality organized to work in water and sanitation?
Who else do you work with in water and sanitation?
**Plant Opinions**
Do you work on the wastewater plant?
Are there good results in the maintenance of the wastewater treatment plant here? Can you give me some examples?
Are there challenges in the maintenance of the wastewater treatment plant here? Can you give me some examples?
What is your opinion of the wastewater plant design?
What do you think is the public opinion about the wastewater plant?
What are your action items towards permanent functionality of the plant?
Do you know about the wastewater laws?
What are the consequences of not obeying the law?
Are there negative effects to humans or the environment from the discharge of wastewater without treating it effectively?
**History**
Can you tell me about the history of wastewater treatment and collection in Leymebamba?
How long has there been a sewage collection system?
What was done before there was a sewage collection system?
How long was the water committee in control of the water and sanitation?
How have the water and sanitation services changed in Leymebamba now that the municipality administers the water?

**Questions to Operator(s)**
**Demographics**
What is your name?
What is your position?
What is your age?
What is your education level?
What is your monthly salary?
**Job Opinions**
What are the primary responsibilities of your job?

What your primary responsibilities in water and sanitation?
What difficulties do you find as the operator of the water and sanitation systems?
Are you satisfied with your work?
Do you have prior experience working in water and sanitation?
Have you received training to work in this position?
How is the municipality organized to work in water and sanitation?
Who else do you work with in water and sanitation?

**Plant and Sewage Collection System Opinions**

Do you work on the wastewater plant?
Could you explain to me briefly how the plant works?
How long have you worked on the plant?
Have you received training on the maintenance of the wastewater plant?
What maintenance is done on the plant?
How often do you perform maintenance?
Are there good results in the maintenance of the wastewater treatment plant here? Can you give me some examples?
Are there challenges in the maintenance of the wastewater treatment plant here? Can you give me some examples?
Why was the plant not able to stay functioning?
What do you think of the…
Size of the plant?
Effectiveness of the plant?
Easiness to maintain?
Bar Screen?
Imhoff Tank?
Filter?
Sludge Drying Bed?
What do you think is the public opinion is about the wastewater plant?
What are your action items towards permanent functionality of the plant?
Are there negative effects to humans or the environment from the discharge of wastewater without treating it effectively?
What parts of Leymebamba are connected to the sewage system? How many houses?
What parts of Leymebamba are not connected to the sewage system? How many houses?
In what condition is the sewage collection system? Does rainwater from the homes also enter the system?
Do you think there is extra water entering the system from leaking toilets and faucets?
What maintenance is performed on the sewage collection system?

**History**

Can you tell me about the history of wastewater collection and treatment in Leymebamba?
How long has there been a sewage collection system?
What was done before there was a sewage collection system?
How long was the water committee in control of the water and sanitation? Who was in charge before that?
How long did you serve on the water committee?
What challenges did the water committee face?
How have the water and sanitation services changed in Leymebamba now that the municipality administers the water?

**Palmira:**

**Questions to Water Committee members**
**Demographics**
What is your name?
What is your position in the water committee?
What is your age?
What is your education level?
What do you do for a living?
**Job Opinions**
What are the primary responsibilities of your position in the water committee?
What do you enjoy about being a member of the water committee?
What difficulties do you find as a member of the water committee?
Are you satisfied with your work?
Why did you want to serve on the water committee?
Have you served on the water committee before?
Have you received training to work in this position?
Does the water committee work together? Can you give me examples?
What have been the successes of the water committee?
How does the community view the water committee?
(To treasurer) Do the funds gained from the water tariffs cover all of the needs of the water committee?
**Plant and Sewage Collection System Opinions**
Do you work on the wastewater plant?
Are there good results in the maintenance of the wastewater treatment plant here? Can you give me some examples?
Are there challenges in the maintenance of the wastewater treatment plant here? Can you give me some examples?
What is your opinion of the wastewater plant design?
What do you think is the public opinion is about the wastewater plant?
Could the maintenance of the wastewater plant be improved? How?
Do you know about the wastewater laws?
What are the consequences of not obeying the law?
Are there negative effects to humans or the environment from the discharge of wastewater without treating it effectively?
**History**
Can you tell me about the history of wastewater treatment and collection in Palmira?
How long has there been a sewage collection system?
What was done before there was a sewage collection system?
How long has the water committee been in control of the water and sanitation? Who was in charge before that?

**Questions to Operator(s)**
**Demographics**
What is your name?
What is your position?
What is your age?
What is your education level?
What is your monthly salary?
What do you do apart from the water committee?
**Job Opinions**

What are the primary responsibilities of your job?
What difficulties do you find as the operator of the water and sanitation systems?
Are you satisfied with your work?
Did you have prior experience working in water and sanitation before obtaining this job?
Have you received training to work in this position?
Why did you want to serve on the water committee?
Have you served on the water committee before?
Have you received training to work in this position?
Does the water committee work together? Can you give me examples?
What have been the successes of the water committee?
How does the community view the water committee?

**Plant and Sewage Collection System Opinions**

Do you work on the wastewater plant?
Could you explain to me briefly how the plant works?
How long have you worked on the plant?
Have you received training on the maintenance of the wastewater plant?
What maintenance is done on the plant?
How often do you perform maintenance?
Are there good results in the maintenance of the wastewater treatment plant here? Can you give me some examples?
Are there challenges in the maintenance of the wastewater treatment plant here? Can you give me some examples?
What do you think of the...
Size of the plant?
Effectiveness of the plant?
Easiness to maintain?
Bar Screen?
Imhoff Tank?
Filter?
Sludge Drying Bed?
What do you think is the public opinion is about the wastewater plant?
Could the maintenance of the wastewater plant be improved? How?
Are there negative effects to humans or the environment from the discharge of wastewater without treating it effectively?
What parts of Palmira are connected to the sewage system? How many houses?
What parts of Palmira are not connected to the sewage system? How many houses?
In what condition is the sewage collection system? Does rainwater from the homes also enter the system?
Do you think there is extra water entering the system from leaking toilets and faucets?
What maintenance is performed on the sewage collection system?

**History**

Can you tell me about the history of wastewater collection and treatment in Palmira?
How long has there been a sewage collection system?
What was done before there was a sewage collection system?
How long has the water committee been in control of the water and sanitation? Who was in charge before that?

## Appendix C: Informed Consent Form in English

Michigan Technological University

# PERMISSION FORM TO PARTICIPATE IN THE STUDY

You are asked to participate in a research study conducted by Rebecca Midkiff and Dr. Alex Mayer from the Department of Environmental Engineering at Michigan Technological University. This study is part of the requirements of the Master's Degree of Ms. Midkiff. Your participation in this study is entirely voluntary. Read the information below and ask questions when you don't understand, before deciding to participate or not.

## NAME OF THE STUDY

"Interventions in the operation and maintenance of wastewater treatment plants in Leymebamba, Amazonas, Peru"

## OBJECTIVE OF THE STUDY

The objective of the study is to find interventions to improve the operation and maintenance of wastewater treatment plants in two towns in Peru. The researcher will work with the local water administration to decide, in a participative manner, what actions to take. Afterwards, the researcher will evaluate the interventions and their effects on the quality and frequency of maintenance to the plant.

## PROCEDURES

If you volunteer to participate in this study, you will be asked to do the following things:

1. Participate in the interviews with the researcher
    - During the course of the study, there will be various interviews (personal and in group) about the plant, maintenance, and your opinions about the interventions, etc. We ask that you answer the questions honestly and cooperatively.
2. Permit the researcher to use your actions and speech in the study in the following way:
    - In the interviews, the responses of the participants will be written down for scientific analysis. The data and observations of plant maintenance also will be recorded for the study.

The study will last until the beginning of December 2015.

## POTENTIAL RISKS

There are minimal risks to you as a participant in this study. The researcher will be observing your work routine and interviewing you. In the event of physical injury and/or mental problems resulting from participation in this study, Michigan Technological University would not provide any medical insurance for participants. Nor would Michigan Technological University provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.

**POTENTIAL BENEFITS TO PARTICIPANTS AND/OR SOCIETY**
The benefits of the study to the participants would be the chance to share their opinions and knowledge about the wastewater plant. The benefits to society would be the acquired knowledge from this study that can be applied to other places in Peru and the world.

**CONFIDENTIALITY**
All of the information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of hiding the identities of the participants with code names in publications and my master's thesis and destroying identifying information at the end of the project. The data in digital form will be kept in the researcher's computer with a security key. The regulations of the Institutional Research Review Board in the United States require that the records are kept for three years after the completion of the final report.

**PARTICIPATION AND WITHDRAWAL**
You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences. You may also refuse to answer any questions you do not want to answer. There is no penalty if you withdraw from the study.

**IDENTIFICATION OF INVESTIGATORS**
If you have any questions or concerns about this research, please contact:

Rebecca Midkiff
Cel. (#) 945052797
360 Jr. José Olaya, Palmira, Leymebamba, Amazonas
Email: Reb.c.midkiff@gmail.com

Dr. Alex Mayer
Email: asmayer@mtu.edu

**RIGHTS OF RESEARCH PARTICIPANTS**
The Institutional Research Review Board at Michigan Technological University has reviewed my request to conduct this project. If you have any concerns about your rights in this study, please contact them at (001) 906-487-2902 or email IRB@mtu.edu.

---

I understand the information above. My questions have been answered well, and I agree to participate in this study. I have received a copy of this document.

________________________________________
Printed Name of Participant

________________________________________ ____________
Signature of Participant Date

Additionally, I give permission to Rebecca Midkiff and Michigan Technological University to use my name and/or the information I provide in a way that is identifiable to me (for example, using my job or position in connection with the information I give in the interview).

________________________________________ ___________

Signature of Participant Date

# Appendix D: BioWin Values

BOD Influent (Constant input)

| Name | Value |
|---|---|
| Flow [m3/d] | 290.00 |
| Total Carbonaceous BOD [mg BOD/L] | 218.00 |
| Volatile suspended solids [mg VSS/L] | 122.00 |
| Total suspended solids [mg TSS/L] | 126.00 |
| Total Kjeldahl Nitrogen [mg N/L] | 70.00 |
| Total Phosphorus [mg P/L] | 12.00 |
| Nitrate [mg N/L] | 0.20 |
| pH [-] | 7.50 |
| Alkalinity [mmol/L] | 3.00 |
| Calcium [mg/L] | 80.00 |
| Magnesium [mg/L] | 15.00 |
| Dissolved oxygen [mg/L] | 2.00 |

Ideal Primary Settling Tank

| Name | Value |
|---|---|
| Volume [m3] | 40.000 |
| Depth [m] | 3.000 |
| Underflow Pacing of BOD Influent [%] | 0.25 |
| Sludge blanket fraction of settler height | 0.10 |
| Constant percent removal [%] | 70.00 |

Anaerobic Digester

| Name | Value |
|---|---|
| Volume [m3] | 60.000 |
| Depth [m] | 2.000 |
| Head space volume [m3] | 50.000 |
| Head space pressure [kPa] | 130.00 |
| Initial liquid hold-up [% of full] | 98.00 |

Anaerobic Digester Outflow Rate Itinerary

| Time [hours] | Flowrate [m3/d] |
|---|---|
| 0 | 0.00 |
| 1795 | 270.00 |
| 1799 | 0.00 |
| **Cycle time 75 days | |
| **Cycle offset 0 days | |

Splitter Flow Split Specification Itinerary

| Time [hours] | Split Fraction [-]* |
|---|---|
| 0 | 0.050 |
| 1795 | 1.000 |
| 1799 | 0.050 |
| *Fraction [S/(S+M)] | |
| **Cycle time 75 days | |
| **Cycle offset 0 days | |

Trickling Filter

| Name | Value |
|---|---|
| Area [m2] | 36.00 |
| Depth [m] | 2.00 |
| Media Type | Rock |
| Specific area [m2/m3] | 50.00 |
| Specific volume [m3/m3] | 0.26 |
| Liquid thickness [mm] | 1.25 |
| Gas transfer effective area fraction [-] | 0.50 |
| Low hydraulic loading rate switch [m/d] | 18.50 |
| High hydraulic loading rate switch [m/d] | 92.50 |
| # layers through film | 1 |
| Boundary layer thickness [µm] | 100.00 |
| Air flow rate [m3/hr, 20C, 1 atm] | 915.00 |

**Global Temperature**

| Name | Value |
|---|---|
| Constant temperature (C) | 15 |

**Common**

| Name | Default | Arrhenius |
|---|---|---|
| Hydrolysis rate [1/d] | 2.1000 | 1.0290 |
| Hydrolysis half sat. [-] | 0.0600 | 1.0000 |
| Anoxic hydrolysis factor [-] | 0.2800 | 1.0000 |
| Anaerobic hydrolysis factor (AS) [-] | 0.0400 | 1.0000 |
| Anaerobic hydrolysis factor (AD) [-] | 0.5000 | 1.0000 |
| Adsorption rate of colloids [L/(mgCOD d)] | 0.1500 | 1.0290 |
| Ammonification rate [L/(mgN d)] | 0.0400 | 1.0290 |
| Assimilative nitrate/nitrite reduction rate [1/d] | 0.5000 | 1.0000 |
| Endogenous products decay rate [1/d] | 0 | 1.0000 |

**AOB**

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 0.9000 | 1.0720 |
| Substrate (NH4) half sat. [mgN/L] | 0.7000 | 1.0000 |
| Byproduct NH4 logistic slope [-] | 50.0000 | 1.0000 |
| Byproduct NH4 inflection point [mgN/L] | 1.4000 | 1.0000 |
| AOB denite DO half sat. [mg/L] | 0.1000 | 1.0000 |
| AOB denite HNO2 half sat. [mgN/L] | 5.000E-6 | 1.0000 |
| Aerobic decay rate [1/d] | 0.1700 | 1.0290 |
| Anoxic/anaerobic decay rate [1/d] | 0.0800 | 1.0290 |
| KiHNO2 [mmol/L] | 0.0050 | 1.0000 |

**NOB**

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 0.7000 | 1.0600 |
| Substrate (NO2) half sat. [mgN/L] | 0.1000 | 1.0000 |
| Aerobic decay rate [1/d] | 0.1700 | 1.0290 |
| Anoxic/anaerobic decay rate [1/d] | 0.0800 | 1.0290 |
| KiNH3 [mmol/L] | 0.0750 | 1.0000 |

AAO

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 0.2000 | 1.1000 |
| Substrate (NH4) half sat. [mgN/L] | 2.0000 | 1.0000 |
| Substrate (NO2) half sat. [mgN/L] | 1.0000 | 1.0000 |
| Aerobic decay rate [1/d] | 0.0190 | 1.0290 |
| Anoxic/anaerobic decay rate [1/d] | 0.0095 | 1.0290 |
| Ki Nitrite [mgN/L] | 1000.0000 | 1.0000 |
| Nitrite sensitivity constant [L / (d mgN) ] | 0.0160 | 1.0000 |

OHO

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 3.2000 | 1.0290 |
| Substrate half sat. [mgCOD/L] | 5.0000 | 1.0000 |
| Anoxic growth factor [-] | 0.5000 | 1.0000 |
| Denite N2 producers (NO3 or NO2) [-] | 0.5000 | 1.0000 |
| Aerobic decay rate [1/d] | 0.6200 | 1.0290 |
| Anoxic decay rate [1/d] | 0.2330 | 1.0290 |
| Anaerobic decay rate [1/d] | 0.1310 | 1.0290 |
| Fermentation rate [1/d] | 1.6000 | 1.0290 |
| Fermentation half sat. [mgCOD/L] | 5.0000 | 1.0000 |
| Fermentation growth factor (AS) [-] | 0.2500 | 1.0000 |
| Free nitrous acid inhibition [mmol/L] | 1.000E-7 | 1.0000 |

Methylotrophs

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 1.3000 | 1.0720 |
| Methanol half sat. [mgCOD/L] | 0.5000 | 1.0000 |
| Denite N2 producers (NO3 or NO2) [-] | 0.5000 | 1.0000 |
| Aerobic decay rate [1/d] | 0.0400 | 1.0290 |
| Anoxic/anaerobic decay rate [1/d] | 0.0300 | 1.0000 |
| Free nitrous acid inhibition [mmol/L] | 1.000E-7 | 1.0000 |

**PAO**

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 0.9500 | 1.0000 |
| Max. spec. growth rate, P-limited [1/d] | 0.4200 | 1.0000 |
| Substrate half sat. [mgCOD(PHB)/mgCOD(Zbp)] | 0.1000 | 1.0000 |
| Substrate half sat., P-limited [mgCOD(PHB)/mgCOD(Zbp)] | 0.0500 | 1.0000 |
| Magnesium half sat. [mgMg/L] | 0.1000 | 1.0000 |
| Cation half sat. [mmol/L] | 0.1000 | 1.0000 |
| Calcium half sat. [mgCa/L] | 0.1000 | 1.0000 |
| Aerobic/anoxic decay rate [1/d] | 0.1000 | 1.0000 |
| Aerobic/anoxic maintenance rate [1/d] | 0 | 1.0000 |
| Anaerobic decay rate [1/d] | 0.0400 | 1.0000 |
| Anaerobic maintenance rate [1/d] | 0 | 1.0000 |
| Sequestration rate [1/d] | 4.5000 | 1.0000 |
| Anoxic growth factor [-] | 0.3300 | 1.0000 |

**Acetogens**

| Name | Default | Arrhenius |
|---|---|---|
| Max. spec. growth rate [1/d] | 0.2500 | 1.0290 |
| Substrate half sat. [mgCOD/L] | 10.0000 | 1.0000 |
| Acetate inhibition [mgCOD/L] | 10000.0000 | 1.0000 |
| Anaerobic decay rate [1/d] | 0.0500 | 1.0290 |
| Aerobic/anoxic decay rate [1/d] | 0.5200 | 1.0290 |

**Methanogens**

| Name | Default | Arrhenius |
|---|---|---|
| Acetoclastic max. spec. growth rate [1/d] | 0.3000 | 1.0290 |
| H2-utilizing max. spec. growth rate [1/d] | 1.4000 | 1.0290 |
| Acetoclastic substrate half sat. [mgCOD/L] | 100.0000 | 1.0000 |
| Acetoclastic methanol half sat. [mgCOD/L] | 0.5000 | 1.0000 |
| H2-utilizing CO2 half sat. [mmol/L] | 0.1000 | 1.0000 |
| H2-utilizing substrate half sat. [mgCOD/L] | 0.1000 | 1.0000 |
| H2-utilizing methanol half sat. [mgCOD/L] | 0.5000 | 1.0000 |
| Acetoclastic propionic inhibition [mgCOD/L] | 10000.0000 | 1.0000 |
| Acetoclastic anaerobic decay rate [1/d] | 0.1300 | 1.0290 |
| Acetoclastic aerobic/anoxic decay rate [1/d] | 0.6000 | 1.0290 |
| H2-utilizing anaerobic decay rate [1/d] | 0.1300 | 1.0290 |
| H2-utilizing aerobic/anoxic decay rate [1/d] | 2.8000 | 1.0290 |

**pH**

| Name | Default |
|---|---|
| OHO low pH limit [-] | 4.0000 |
| OHO high pH limit [-] | 10.0000 |
| Methylotrophs low pH limit [-] | 4.0000 |
| Methylotrophs high pH limit [-] | 10.0000 |
| Autotrophs low pH limit [-] | 5.5000 |
| Autotrophs high pH limit [-] | 9.5000 |
| PAO low pH limit [-] | 4.0000 |
| PAO high pH limit [-] | 10.0000 |
| OHO low pH limit (anaerobic) [-] | 5.5000 |
| OHO high pH limit (anaerobic) [-] | 8.5000 |
| Propionic acetogens low pH limit [-] | 4.0000 |
| Propionic acetogens high pH limit [-] | 10.0000 |
| Acetoclastic methanogens low pH limit [-] | 5.0000 |
| Acetoclastic methanogens high pH limit [-] | 9.0000 |
| H2-utilizing methanogens low pH limit [-] | 5.0000 |
| H2-utilizing methanogens high pH limit [-] | 9.0000 |

**Switches**

| Name | Default |
|---|---|
| Aerobic/anoxic DO half sat. [mgO2/L] | 0.0500 |
| Anoxic/anaerobic NOx half sat. [mgN/L] | 0.1500 |
| AOB DO half sat. [mgO2/L] | 0.2500 |
| NOB DO half sat. [mgO2/L] | 0.5000 |
| AAO DO half sat. [mgO2/L] | 0.0100 |
| Anoxic NO3(->NO2) half sat. [mgN/L] | 0.1000 |
| Anoxic NO3(->N2) half sat. [mgN/L] | 0.0500 |
| Anoxic NO2(->N2) half sat. (mgN/L) | 0.0100 |
| NH3 nutrient half sat. [mgN/L] | 0.0050 |
| PolyP half sat. [mgP/mgCOD] | 0.0100 |
| VFA sequestration half sat. [mgCOD/L] | 5.0000 |
| P uptake half sat. [mgP/L] | 0.1500 |
| P nutrient half sat. [mgP/L] | 0.0010 |
| Autotroph CO2 half sat. [mmol/L] | 0.1000 |
| H2 low/high half sat. [mgCOD/L] | 1.0000 |
| Propionic acetogens H2 inhibition [mgCOD/L] | 5.0000 |
| Synthesis anion/cation half sat. [meq/L] | 0.0100 |

**Common**

| Name | Default |
|---|---|
| Biomass volatile fraction (VSS/TSS) | 0.9200 |
| Endogenous residue volatile fraction (VSS/TSS) | 0.9200 |
| N in endogenous residue [mgN/mgCOD] | 0.0700 |
| P in endogenous residue [mgP/mgCOD] | 0.0220 |
| Endogenous residue COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |
| Particulate substrate COD:VSS ratio [mgCOD/mgVSS] | 1.6000 |
| Particulate inert COD:VSS ratio [mgCOD/mgVSS] | 1.6000 |

**AOB**

| Name | Default |
|---|---|
| Yield [mgCOD/mgN] | 0.1500 |
| AOB denite NO2 fraction as TEA [-] | 0.5000 |
| Byproduct NH4 fraction to N2O [-] | 0.0025 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous residue [-] | 0.0800 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |

**NOB**

| Name | Default |
|---|---|
| Yield [mgCOD/mgN] | 0.0900 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous residue [-] | 0.0800 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |

**AAO**

| Name | Default |
|---|---|
| Yield [mgCOD/mgN] | 0.1140 |
| Nitrate production [mgN/mgBiomassCOD] | 2.2800 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous residue [-] | 0.0800 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |

OHO

| Name | Default |
|---|---|
| Yield (aerobic) [-] | 0.6660 |
| Yield (fermentation, low H2) [-] | 0.1000 |
| Yield (fermentation, high H2) [-] | 0.1000 |
| H2 yield (fermentation low H2) [-] | 0.3500 |
| H2 yield (fermentation high H2) [-] | 0 |
| Propionate yield (fermentation, low H2) [-] | 0 |
| Propionate yield (fermentation, high H2) [-] | 0.7000 |
| CO2 yield (fermentation, low H2) [-] | 0.7000 |
| CO2 yield (fermentation, high H2) [-] | 0 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Endogenous fraction - aerobic [-] | 0.0800 |
| Endogenous fraction - anoxic [-] | 0.1030 |
| Endogenous fraction - anaerobic [-] | 0.1840 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |
| Yield (anoxic) [-] | 0.5400 |
| Yield propionic (aerobic) [-] | 0.6400 |
| Yield propionic (anoxic) [-] | 0.4600 |
| Yield acetic (aerobic) [-] | 0.6000 |
| Yield acetic (anoxic) [-] | 0.4300 |
| Yield methanol (aerobic) [-] | 0.5000 |
| Adsorp. max. [-] | 1.0000 |
| Max fraction to N2O at high FNA over nitrate [-] | 0.0500 |
| Max fraction to N2O at high FNA over nitrite [-] | 0.1000 |

**Methylotrophs**

| Name | Default |
|---|---|
| Yield (anoxic) [-] | 0.4000 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous residue [-] | 0.0800 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |
| Max fraction to N2O at high FNA over nitrate [-] | 0.1000 |
| Max fraction to N2O at high FNA over nitrite [-] | 0.1500 |

**PAO**

| Name | Default |
|---|---|
| Yield (aerobic) [-] | 0.6390 |
| Yield (anoxic) [-] | 0.5200 |
| Aerobic P/PHA uptake [mgP/mgCOD] | 0.9300 |
| Anoxic P/PHA uptake [mgP/mgCOD] | 0.3500 |
| Yield of PHA on sequestration [-] | 0.8890 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| N in sol. inert [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous part. [-] | 0.2500 |
| Inert fraction of endogenous sol. [-] | 0.2000 |
| P/Ac release ratio [mgP/mgCOD] | 0.5100 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |
| Yield of low PP [-] | 0.9400 |

**Acetogens**

| Name | Default |
|---|---|
| Yield [-] | 0.1000 |
| H2 yield [-] | 0.4000 |
| CO2 yield [-] | 1.0000 |
| N in biomass [mgN/mgCOD] | 0.0700 |
| P in biomass [mgP/mgCOD] | 0.0220 |
| Fraction to endogenous residue [-] | 0.0800 |
| COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |

Methanogens

| Name | Default |
|---|---|
| Acetoclastic yield [-] | 0.1000 |
| Methanol acetoclastic yield [-] | 0.1000 |
| H2-utilizing yield [-] | 0.1000 |
| Methanol H2-utilizing yield [-] | 0.1000 |
| N in acetoclastic biomass [mgN/mgCOD] | 0.0700 |
| N in H2-utilizing biomass [mgN/mgCOD] | 0.0700 |
| P in acetoclastic biomass [mgP/mgCOD] | 0.0220 |
| P in H2-utilizing biomass [mgP/mgCOD] | 0.0220 |
| Acetoclastic fraction to endog. residue [-] | 0.0800 |
| H2-utilizing fraction to endog. residue [-] | 0.0800 |
| Acetoclastic COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |
| H2-utilizing COD:VSS ratio [mgCOD/mgVSS] | 1.4200 |

General

| Name | Default |
|---|---|
| Molecular weight of other anions [mg/mmol] | 35.5000 |
| Molecular weight of other cations [mg/mmol] | 39.1000 |
| Mg to P mole ratio in polyphosphate [mmolMg/mmolP] | 0.3000 |
| Cation to P mole ratio in polyphosphate [meq/mmolP] | 0.1500 |
| Ca to P mole ratio in polyphosphate [mmolCa/mmolP] | 0.0500 |
| Cation to P mole ratio in organic phosphate [meq/mmolP] | 0.0100 |
| Bubble rise velocity (anaerobic digester) [cm/s] | 23.9000 |
| Bubble Sauter mean diameter (anaerobic digester) [cm] | 0.3500 |
| Anaerobic digester gas hold-up factor [] | 1.0000 |
| Tank head loss per metre of length (from flow) [m/m] | 0.0025 |

**Mass transfer**

| Name | Default | Arrhenius |
|---|---|---|
| Kl for H2 [m/d] | 17.0000 | 1.0240 |
| Kl for CO2 [m/d] | 10.0000 | 1.0240 |
| Kl for NH3 [m/d] | 1.0000 | 1.0240 |
| Kl for CH4 [m/d] | 8.0000 | 1.0240 |
| Kl for N2 [m/d] | 15.0000 | 1.0240 |
| Kl for N2O [m/d] | 8.0000 | 1.0240 |
| Kl for O2 [m/d] | 13.0000 | 1.0240 |

**Henry's law constants**

| Name | Default | Arrhenius |
|---|---|---|
| CO2 [M/atm] | 0.0340 | 2400.0000 |
| O2 [M/atm] | 0.0013 | 1500.0000 |
| N2 [M/atm] | 6.500E-4 | 1300.0000 |
| N2O [M/atm] | 0.0250 | 2600.0000 |
| NH3 [M/atm] | 58.0000 | 4100.0000 |
| CH4 [M/atm] | 0.0014 | 1600.0000 |
| H2 [M/atm] | 7.800E-4 | 500.0000 |

**Physico-chemical rates**

| Name | Default | Arrhenius |
|---|---|---|
| Struvite precipitation rate [1/d] | 3.000E+10 | 1.0240 |
| Struvite redissolution rate [1/d] | 3.000E+11 | 1.0240 |
| Struvite half sat. [mgTSS/L] | 1.0000 | 1.0000 |
| HDP precipitation rate [L/(molP d)] | 1.000E+8 | 1.0000 |
| HDP redissolution rate [L/(mol P d)] | 1.000E+8 | 1.0000 |
| HAP precipitation rate [molHDP/(L d)] | 5.000E-4 | 1.0000 |

**Physico-chemical constants**

| Name | Default |
|---|---|
| Struvite solubility constant [mol/L] | 6.918E-14 |
| HDP solubility product [mol/L] | 2.750E-22 |
| HDP half sat. [mgTSS/L] | 1.0000 |
| Equilibrium soluble PO4 with Al dosing at pH 7 [mgP/L] | 0.0100 |
| Al to P ratio [molAl/molP] | 0.8000 |
| Al(OH)3 solubility product [mol/L] | 1.259E+9 |
| AlHPO4+ dissociation constant [mol/L] | 7.943E-13 |
| Equilibrium soluble PO4 with Fe dosing at pH 7 [mgP/L] | 0.0100 |
| Fe to P ratio [molFe/molP] | 1.6000 |
| Fe(OH)3 solubility product [mol/L] | 0.0500 |
| FeH2PO4++ dissociation constant [mol/L] | 5.012E-22 |

**Aeration**

| Name | Default |
|---|---|
| Alpha (surf) OR Alpha F (diff) [-] | 0.5000 |
| Beta [-] | 0.9500 |
| Surface pressure [kPa] | 101.3250 |
| Fractional effective saturation depth (Fed) [-] | 0.3250 |
| Supply gas CO2 content [vol. %] | 0.0350 |
| Supply gas O2 [vol. %] | 20.9500 |
| Off-gas CO2 [vol. %] | 2.0000 |
| Off-gas O2 [vol. %] | 18.8000 |
| Off-gas H2 [vol. %] | 0 |
| Off-gas NH3 [vol. %] | 0 |
| Off-gas CH4 [vol. %] | 0 |
| Surface turbulence factor [-] | 2.0000 |
| Set point controller gain [] | 1.0000 |

**Modified Vesilind**

| Name | Default |
|---|---|
| Maximum Vesilind settling velocity (Vo) [m/d] | 170.000 |
| Vesilind hindered zone settling parameter (K) [L/g] | 0.370 |
| Clarification switching function [mg/L] | 100.0000 |
| Specified TSS conc.for height calc. [mg/L] | 2500.0000 |
| Maximum compactability constant [mg/L] | 1.500E+4 |

**Double exponential**

| Name | Default |
|---|---|
| Maximum Vesilind settling velocity (Vo) [m/d] | 410.000 |
| Maximum (practical) settling velocity (Vo') [m/d] | 270.000 |
| Hindered zone settling parameter (Kh) [L/g] | 0.400 |
| Flocculent zone settling parameter (Kf) [L/g] | 2.500 |
| Maximum non-settleable TSS [mg/L] | 20.00000 |
| Non-settleable fraction [-] | 0.00100 |
| Specified TSS conc. for height calc. [mg/L] | 2500.00000 |

**Emission factors**

| Name | Default |
|---|---|
| Carbon dioxide equivalence of nitrous oxide | 296.0000 |
| Carbon dioxide equivalence of methane | 23.0000 |

**Biofilm general**

| Name | Default | Arrhenius |
|---|---|---|
| Attachment rate [ g / (m2 d) ] | 80.0000 | 1.0000 |
| Attachment TSS half sat. [mg/L] | 100.0000 | 1.0000 |
| Detachment rate [g/(m3 d)] | 8.000E+4 | 1.0000 |
| Solids movement factor [] | 10.0000 | 1.0000 |
| Diffusion neta [] | 0.8000 | 1.0000 |
| Thin film limit [mm] | 0.5000 | 1.0000 |
| Thick film limit [mm] | 3.0000 | 1.0000 |
| Assumed Film thickness for tank volume correction (temp independent) [mm] | 0.7500 | 1.0000 |
| Film surface area to media area ratio - Max.[ ] | 1.0000 | 1.0000 |
| Minimum biofilm conc. for streamer formation [gTSS/m2] | 4.0000 | 1.0000 |

Maximum biofilm concentrations [mg/L]

| Name | Default | Arrhenius |
|---|---|---|
| Ordinary heterotrophic organisms (OHO) | 5.000E+4 | 1.0000 |
| Methylotrophs | 5.000E+4 | 1.0000 |
| Ammonia oxidizing biomass (AOB) | 1.000E+5 | 1.0000 |
| Nitrite oxidizing biomass (NOB) | 1.000E+5 | 1.0000 |
| Anaerobic ammonia oxidizers (AAO) | 5.000E+4 | 1.0000 |
| Polyphosphate accumulating organisms (PAO) | 5.000E+4 | 1.0000 |
| Propionic acetogens | 5.000E+4 | 1.0000 |
| Methanogens - acetoclastic | 5.000E+4 | 1.0000 |
| Methanogens - hydrogenotrophic | 5.000E+4 | 1.0000 |
| Endogenous products | 3.000E+4 | 1.0000 |
| Slowly bio. COD (part.) | 5000.0000 | 1.0000 |
| Slowly bio. COD (colloid.) | 4000.0000 | 1.0000 |
| Part. inert. COD | 5000.0000 | 1.0000 |
| Part. bio. org. N | 0 | 1.0000 |
| Part. bio. org. P | 0 | 1.0000 |
| Part. inert N | 0 | 1.0000 |
| Part. inert P | 0 | 1.0000 |
| Stored PHA | 5000.0000 | 1.0000 |
| Releasable stored polyP | 1.150E+6 | 1.0000 |
| Fixed stored polyP | 1.150E+6 | 1.0000 |
| Readily bio. COD (complex) | 0 | 1.0000 |
| Acetate | 0 | 1.0000 |
| Propionate | 0 | 1.0000 |
| Methanol | 0 | 1.0000 |
| Dissolved H2 | 0 | 1.0000 |
| Dissolved methane | 0 | 1.0000 |
| Ammonia N | 0 | 1.0000 |
| Sol. bio. org. N | 0 | 1.0000 |
| Nitrous Oxide N | 0 | 1.0000 |
| Nitrite N | 0 | 1.0000 |
| Nitrate N | 0 | 1.0000 |
| Dissolved nitrogen gas | 0 | 1.0000 |
| PO4-P (Sol. & Me Complexed) | 1.000E+10 | 1.0000 |
| Sol. inert COD | 0 | 1.0000 |
| Sol. inert TKN | 0 | 1.0000 |
| ISS Influent | 1.300E+6 | 1.0000 |
| Struvite | 8.500E+5 | 1.0000 |

## Effective diffusivities [m2/s]

| Name | Default | Arrhenius |
|---|---|---|
| Ordinary heterotrophic organisms (OHO) | 5.000E-14 | 1.0290 |
| Methylotrophs | 5.000E-14 | 1.0290 |
| Ammonia oxidizing biomass (AOB) | 5.000E-14 | 1.0290 |
| Nitrite oxidizing biomass (NOB) | 5.000E-14 | 1.0290 |
| Anaerobic ammonia oxidizers (AAO) | 5.000E-14 | 1.0290 |
| Polyphosphate accumulating organisms (PAO) | 5.000E-14 | 1.0290 |
| Propionic acetogens | 5.000E-14 | 1.0290 |
| Methanogens - acetoclastic | 5.000E-14 | 1.0290 |
| Methanogens - hydrogenotrophic | 5.000E-14 | 1.0290 |
| Endogenous products | 5.000E-14 | 1.0290 |
| Slowly bio. COD (part.) | 5.000E-14 | 1.0290 |
| Slowly bio. COD (colloid.) | 5.000E-12 | 1.0290 |
| Part. inert. COD | 5.000E-14 | 1.0290 |
| Part. bio. org. N | 5.000E-14 | 1.0290 |
| Part. bio. org. P | 5.000E-14 | 1.0290 |
| Part. inert N | 5.000E-14 | 1.0290 |
| Part. inert P | 5.000E-14 | 1.0290 |
| Stored PHA | 5.000E-14 | 1.0290 |
| Releasable stored polyP | 5.000E-14 | 1.0290 |
| Fixed stored polyP | 5.000E-14 | 1.0290 |
| Readily bio. COD (complex) | 6.900E-10 | 1.0290 |
| Acetate | 1.240E-9 | 1.0290 |
| Propionate | 8.300E-10 | 1.0290 |
| Methanol | 1.600E-9 | 1.0290 |
| Dissolved H2 | 5.850E-9 | 1.0290 |
| Dissolved methane | 1.963E-9 | 1.0290 |
| Ammonia N | 2.000E-9 | 1.0290 |
| Sol. bio. org. N | 1.370E-9 | 1.0290 |
| Nitrous Oxide N | 1.607E-9 | 1.0290 |
| Nitrite N | 2.980E-9 | 1.0290 |
| Nitrate N | 2.980E-9 | 1.0290 |
| Dissolved nitrogen gas | 1.900E-9 | 1.0290 |
| PO4-P (Sol. & Me Complexed) | 2.000E-9 | 1.0290 |
| Sol. inert COD | 6.900E-10 | 1.0290 |
| Sol. inert TKN | 6.850E-10 | 1.0290 |
| ISS Influent | 5.000E-14 | 1.0290 |
| Struvite | 5.000E-14 | 1.0290 |
| Hydroxy-dicalcium-phosphate | 5.000E-14 | 1.0290 |
| Hydroxy-apatite | 5.000E-14 | 1.0290 |
| Magnesium | 7.200E-10 | 1.0290 |
| Calcium | 7.200E-10 | 1.0290 |
| Metal | 4.800E-10 | 1.0290 |
| Other Cations (strong bases) | 1.440E-9 | 1.0290 |
| Other Anions (strong acids) | 1.440E-9 | 1.0290 |
| Total CO2 | 1.960E-9 | 1.0290 |
| User defined 1 | 6.900E-10 | 1.0290 |
| User defined 2 | 6.900E-10 | 1.0290 |
| User defined 3 | 5.000E-14 | 1.0290 |
| User defined 4 | 5.000E-14 | 1.0290 |
| Dissolved oxygen | 2.500E-9 | 1.0290 |

## EPS Strength coefficients [ ]

| Name | Default | Arrhenius |
|---|---|---|
| Ordinary heterotrophic organisms (OHO) | 1.0000 | 1.0000 |
| Methylotrophs | 1.0000 | 1.0000 |
| Ammonia oxidizing biomass (AOB) | 5.0000 | 1.0000 |
| Nitrite oxidizing biomass (NOB) | 25.0000 | 1.0000 |
| Anaerobic ammonia oxidizers (AAO) | 10.0000 | 1.0000 |
| Polyphosphate accumulating organisms (PAO) | 1.0000 | 1.0000 |
| Propionic acetogens | 1.0000 | 1.0000 |
| Methanogens - acetoclastic | 1.0000 | 1.0000 |
| Methanogens - hydrogenotrophic | 1.0000 | 1.0000 |
| Endogenous products | 1.0000 | 1.0000 |
| Slowly bio. COD (part.) | 1.0000 | 1.0000 |
| Slowly bio. COD (colloid.) | 1.0000 | 1.0000 |
| Part. inert. COD | 1.0000 | 1.0000 |
| Part. bio. org. N | 1.0000 | 1.0000 |
| Part. bio. org. P | 1.0000 | 1.0000 |
| Part. inert N | 1.0000 | 1.0000 |
| Part. inert P | 1.0000 | 1.0000 |
| Stored PHA | 1.0000 | 1.0000 |
| Releasable stored polyP | 1.0000 | 1.0000 |
| Fixed stored polyP | 1.0000 | 1.0000 |
| Readily bio. COD (complex) | 0 | 1.0000 |
| Acetate | 0 | 1.0000 |
| Propionate | 0 | 1.0000 |
| Methanol | 0 | 1.0000 |
| Dissolved H2 | 0 | 1.0000 |
| Dissolved methane | 0 | 1.0000 |
| Ammonia N | 0 | 1.0000 |
| Sol. bio. org. N | 0 | 1.0000 |
| Nitrous Oxide N | 0 | 1.0000 |
| Nitrite N | 0 | 1.0000 |
| Nitrate N | 0 | 1.0000 |
| Dissolved nitrogen gas | 0 | 1.0000 |
| PO4-P (Sol. & Me Complexed) | 1.0000 | 1.0000 |
| Sol. inert COD | 0 | 1.0000 |
| Sol. inert TKN | 0 | 1.0000 |
| ISS Influent | 0.3300 | 1.0000 |
| Struvite | 1.0000 | 1.0000 |
| Hydroxy-dicalcium-phosphate | 1.0000 | 1.0000 |
| Hydroxy-apatite | 1.0000 | 1.0000 |
| Magnesium | 0 | 1.0000 |
| Calcium | 0 | 1.0000 |
| Metal | 1.0000 | 1.0000 |
| Other Cations (strong bases) | 0 | 1.0000 |
| Other Anions (strong acids) | 0 | 1.0000 |
| Total CO2 | 0 | 1.0000 |
| User defined 1 | 0 | 1.0000 |
| User defined 2 | 0 | 1.0000 |
| User defined 3 | 1.0000 | 1.0000 |
| User defined 4 | 1.0000 | 1.0000 |
| Dissolved oxygen | 0 | 1.0000 |

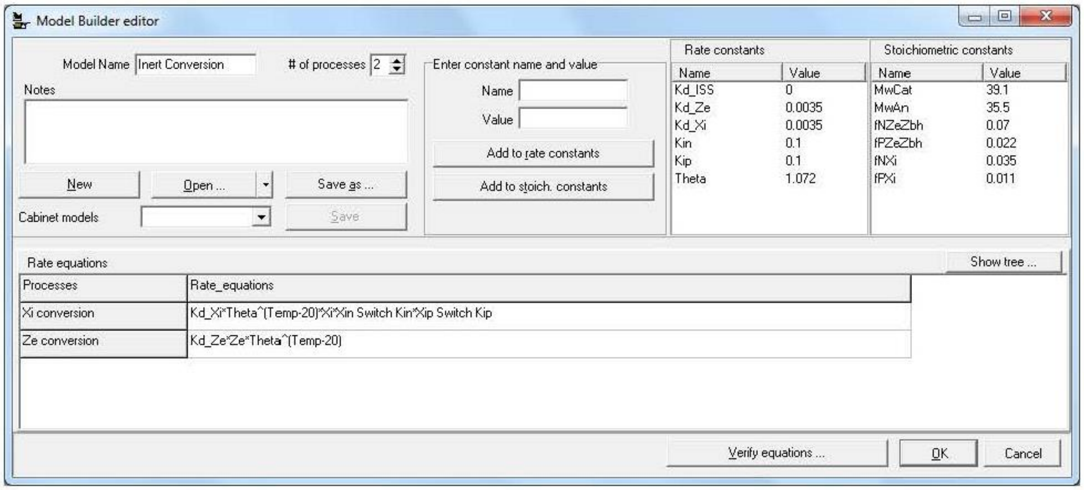
**Influent WW Fractions**

| Name | Default | Value |
|---|---|---|
| Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD] | 0.1600 | 0.1600 |
| Fac - Acetate [gCOD/g of readily biodegradable COD] | 0.1500 | 0.1500 |
| Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD] | 0.7500 | 0.4900 |
| Fus - Unbiodegradable soluble [gCOD/g of total COD] | 0.0500 | 0.0500 |
| Fup - Unbiodegradable particulate [gCOD/g of total COD] | 0.1300 | 0.1300 |
| Fna - Ammonia [gNH3-N/gTKN] | 0.6600 | 0.6600 |
| Fnox - Particulate organic nitrogen [gN/g Organic N] | 0.5000 | 0.5000 |
| Fnus - Soluble unbiodegradable TKN [gN/gTKN] | 0.0200 | 0.0200 |
| FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD] | 0.0350 | 0.0350 |
| Fpo4 - Phosphate [gPO4-P/gTP] | 0.5000 | 0.5000 |
| FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD] | 0.0110 | 0.0110 |
| FZbh - OHO COD fraction [gCOD/g of total COD] | 0.0200 | 0.0200 |
| FZbm - Methylotroph COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZaob - AOB COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZnob - NOB COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZaao - AAO COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZbp - PAO COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZbpa - Propionic acetogens COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZbam - Acetoclastic methanogens COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZbhm - H2-utilizing methanogens COD fraction [gCOD/g of total COD] | 1.000E-4 | 1.000E-4 |
| FZe - Endogenous products COD fraction [gCOD/g of total COD] | 0 | 0 |

**Anaerobic Digester Seed Concentrations**

| State variable | Units | Value |
|---|---|---|
| Ordinary heterotrophic organisms (OHO) | mgCOD/L | 0 |
| Methylotrophs | mgCOD/L | 0 |
| Ammonia oxidizing biomass (AOB) | mgCOD/L | 0 |
| Nitrite oxidizing biomass (NOB) | mgCOD/L | 0 |
| Anaerobic ammonia oxidizers (AAO) | mgCOD/L | 0 |
| Polyphosphate accumulating organisms (PAO) | mgCOD/L | 0 |
| Propionic acetogens | mgCOD/L | 0 |
| Methanogens - acetoclastic | mgCOD/L | 0 |
| Methanogens - hydrogenotrophic | mgCOD/L | 0 |
| Endogenous products | mgCOD/L | 0 |
| Slowly bio. COD (part.) | mgCOD/L | 0 |
| Slowly bio. COD (colloid.) | mgCOD/L | 0 |
| Part. inert. COD | mgCOD/L | 0 |
| Part. bio. org. N | mgN/L | 0 |
| Part. bio. org. P | mgP/L | 0 |
| Part. inert N | mgN/L | 0 |
| Part. inert P | mgP/L | 0 |
| Stored PHA | mgCOD/L | 0 |
| Releasable stored polyP | mgP/L | 0 |
| Fixed stored polyP | mgP/L | 0 |
| Readily bio. COD (complex) | mgCOD/L | 0 |
| Acetate | mgCOD/L | 0 |
| Propionate | mgCOD/L | 0 |
| Methanol | mgCOD/L | 0 |
| Dissolved H2 | mgCOD/L | 0 |
| Dissolved methane | mg/L | 0 |
| Ammonia N | mgN/L | 0 |
| Sol. bio. org. N | mgN/L | 0 |
| Nitrous Oxide N | mgN/L | 0 |
| Nitrite N | mgN/L | 0 |
| Nitrate N | mgN/L | 0 |
| Dissolved nitrogen gas | mgN/L | 0 |
| PO4-P (Sol. & Me Complexed) | mgP/L | 0 |
| Sol. inert COD | mgCOD/L | 0 |
| Sol. inert TKN | mgN/L | 0 |
| ISS Influent | mgISS/L | 0 |
| Struvite | mgISS/L | 0 |
| Hydroxy-dicalcium-phosphate | mgISS/L | 0 |
| Hydroxy-apatite | mgISS/L | 0 |
| Magnesium | mg/L | 0 |
| Calcium | mg/L | 0 |
| Metal | mg/L | 0 |
| Other Cations (strong bases) | meq/L | 0 |
| Other Anions (strong acids) | meq/L | 0 |
| Total CO2 | mmol/L | 7.000 |
| User defined 1 | mg/L | 0 |
| User defined 2 | mg/L | 0 |
| User defined 3 | mgVSS/L | 0 |
| User defined 4 | mgISS/L | 0 |
| Dissolved oxygen | mg/L | 0 |

## Model Builder Constants and Rate Equations




## Model Builder Stoichiometric Parameters

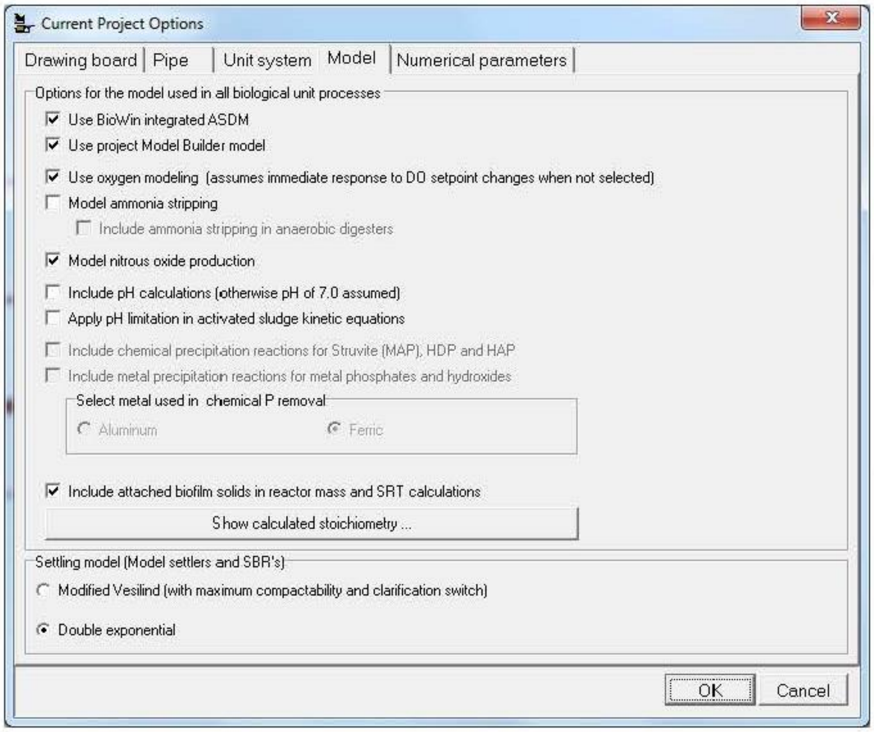
| Processes | Zbh | Zbmeth | Zaob | Znob | Zaao | Zbp | Zbpa | Zbam | Zbhm | Ze | Xsp | Xsc | Xi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Xi Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 0.0 | -1 |
| Ze Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -1 | 1 | 0.0 | 0.0 |

| Processes | Xon | Xop | Xin | Xip | Sphb | PPlo | PPhi | Sbsc | Sbsa | Sbsp | Sbmeth |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Xi Conversion | +fNXi | +fPXi | -fNXi | -fPXi | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ze Conversion | +fNZeZbh | +fPZeZbh | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Processes | SbH2 | CH4 | NH3N | Nos | N2ON | NO2N | NO3N | N2 | PO4P | Sus | Nus | ISS | XStru |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Xi Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ze Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Processes | XHDP | XHAP | Mg | SCa | Me | SCat | SAn | SCO2 | UD1 | UD2 | UD3 | UD4 | DO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Xi Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ze Conversion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## Current Project Options - Model




## Current Project Options – Numerical Parameters