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Wastewater treatment alternatives for an urban neighborhood in Cochabamba, Bolivia

A single-case study of a neighborhood and its wastewater treatment system

Master of Science Thesis in Environmental Science

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Cover:
Cloth washing in The River Rocha outside Cochabamba at Puente Huayllni (private photo)

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Abstract

The aim of this master thesis is to describe the wastewater treatment system and suggest improvements for a neighborhood located between Cochabamba and Sacaba. For the moment, the neighborhood uses a self-constructed septic tank as a part of their waste water treatment system. Water samples were taken before and after the septic tank to evaluate the efficiency. Samples were taken at two different times and in between the tank was emptied by a sewage lorry. To find out why the tank is not maintained better have qualitative interviews been performed and the results of these have formed the basis of an MCA-analysis which aimed to propose how this residential area can improve their wastewater treatment system. A sampling session was also made from the Rio Rocha to determine the degree of contamination and to be able to describe the differences between the dry and rainy season.

From interviews it was concluded that the septic tank is misconstrued and therefore have never been emptied. Sample results from the outflow from the septic tank do not show any improvement. The effectiveness of the septic tank is very bad and therefore the wastewater that flows through the septic tank is discharged directly into the river without undergoing any type of treatment.

Interview results show that the primary reason why the wastewater treatment is insufficient in this neighborhood is not lack of knowledge but rather organizational challenges and lack of money. The results from the interviews formed the basis of the MCA-analysis, where simple and inexpensive solutions with minimal landscape impact have been promoted. An anaerobic biogas reactor with a connected constructed wetland was chosen as the best solution for the neighborhood's wastewater. It's highly recommended that the neighborhood implement this technique, since this technology already is operating in other areas of Cochabamba. The matrix from the MCA-analysis can easily be changed with respect to both the given points as well as the solutions included in it. This enables the cooperative in this area to use the matrix as a tool for comparing different wastewater treatment options.

The sample results from the Rio Rocha showed decreased flows during the dry season. The concentrations of coliforms are consistently high, exceeding existing limits. Overall, the water quality in the Rio Rocha is very poor. This is largely because many neighborhoods, such as this studied one, discharge their wastewater into the river without sufficient treatment.

Keywords: Wastewater treatment, septic tank, case study, MCA analysis, water sampling, Bolivia, Cochabamba

Avloppsvattenreningsalternativ för en stadsdel i Cochabamba, Bolivia

En fallstudie av ett grannskap och deras avloppsvattenreningssystem

ANNIE ARNOLD

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Sammanfattning

Målet med den här masteruppsatsen är att beskriva avloppsvattenreningssystemet samt föreslå förbättringar i ett mindre samhälle som använder sig av en egenkonstruerad septiktank som en del av deras nuvarande reningssystem. Systemets effektivitet har utvärderats med hjälp av vattenprovtagning före och efter septiktanken. Prover togs vid två olika tillfällen och där emellan rengjordes tanken med hjälp av ett slamsugningsföretag. För att ta reda på varför tanken inte underhålls bättre har kvalitativa intervjuer genomförts och resultaten från dessa har legat till grund för den MCA-analys som utförts vars syfte var att kunna föreslå hur detta samhälle kan förbättra sitt reningssystem. En provtagningsserie har även gjorts från floden Rio Rocha för att fastställa föroreningsgraden av denna samt kunna beskriva skillnaderna mellan torr- och regnsäsong.

I intervjuer framkom det att septiktanken är felkonstruerad och därför aldrig har underhållits. Effektiviteten hos septiktanken är mycket dålig och kan jämnställas med att avloppsvatten som passerar tanken släpps rakt ut i floden utan att genomgå någon typ av behandling. Resultaten från intervjuerna visar även att det primära problemet med detta samhälles vattenreningssystem inte är bristande kunskap utan snarare organisationssvårigheter och brist på pengar. Dessa intervjuresultat har legat till grund för MCA-analysen där enkla och billiga lösningar med minimal landskapspåverkan har främjats. Anaerobic biogas reactor med ett efterföljande constructed wetland valdes som den bästa lösningen för detta samhälles avloppsvatten. Det studerade samhället rekommenderas att implementera denna teknik då denna avloppsvattenreningslösning redan är etablerad i Cochabamba med goda resultat. Matrisen som tagits fram vid MCA-analysen kan även ändras med avseende på såväl poängsättning som vilka lösningar som ingår i den. Detta möjliggör att kooperativet i detta bostadsområde själva kan använda matrisen som ett verktyg för att jämföra olika vattenreningsalternativ.

Provtagningarna från floden Rio Rocha visade på minskade flöden under torrsäsongen. Koncentrationen av koliforma bakterier är genomgående hög och överskrider befintliga gränsvärden. Överlag är vattenkvalitén i Rio Rocha dålig vilket till stor del beror på att många mindre samhällen liknande det område som har studerats släpper ut sitt avloppsvatten i floden utan att behandla det fullständigt.

Nyckelord: Avloppsvattenrening, septiktank, fallstudie, MCA-analys, vattenprovtagning, Bolivia, Cochabamba

Preface

I would like to start this report with saying thank you to everyone who has been involved in my project and helped me to make it possible. My stay in Cochabamba was a really fantastic experience, and I'm really glad that I got this opportunity. I have met so many fantastic people, both during my work and during my spare time in Cochabamba, thank you so much to all of you!

I would specially like to thank Ida Helgegren, Alvaro Guzmán Mercado, Olver Coronado Rocha and Sebastien Rauch for all the help and support during my work. Thank you so much Ida Helgegren for letting me be a part of you PhD project, thank you Alvaro Guzmán Mercado and Olver Coronado Rocha for letting me work together with the University San Simon and CASA, and thank you Sebastien Rauch for all the help and support during my project. I would also like to say thank you to Sulmayra Zarate Guzman for the help during all the water sampling sessions, your support has meant a lot to me! I would also like to include a special thanks to the cooperative, who has made this work possible, both employees, members of the board and users.

Finally, I would like to say thank you to my friend Simón who has been very friendly during my whole stay in Cochabamba. Thanks to you I got the opportunity to see many places in Cochabamba and meet a bunch of nice people, you really made my stay memorable.

I would also like to thank you to ÅF, SIDA and Iris Stipendiet for the financial support.

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1. Introduction

Bolivia is one of the poorest countries in South America and 65 % of the population lives below the national poverty line (UNDP 2009). The climate of Bolivia varies from cool highland climate in the west to tropical lowlands in the east.

Figure 1. Bolivia on the South America map (Genesio 2011).

Cochabamba is located 2 500 meters above sea level in a valley called The Central Valley of Cochabamba, surrounded by the Cordillera Oriental mountains. The city has a pleasant climate all year round with an average temperature of 17.5 degrees and an annual rainfall of 400 - 500 mm. The rainy season is between October and April, while the rest of the year the climate is much drier (Neumann-Redlin, Renner and Torres 2000).The city is the third largest city in Bolivia and has a population of around one million inhabitants. The population is rapidly growing and between 2001 and 2008 the estimated population growth was 3.9 % (Ledo 2009). The population is increasing not only in the centre but also outside the city, which has increased the demand for access of sewer systems as well as drinking water.

1.1 Environmental challenges

Both the collection of garbage as well as wastewater treatment is inadequate in many areas in Cochabamba, particularly in the southern parts. The capacity of the municipal wastewater treatment plant in Cochabamba is too small to serve the growing population. Hence, polluted water is discharged from the wastewater treatment plant causing contamination in the surrounding environment (Ledo 2009). When it comes to drinking water about half of the population in the metropolitan area of Cochabamba uses the municipal system SEMAPA. The remaining part of the population gets their drinking water from wells built by community-based organizations, private wells or from water trucks. Drinking water bought from water trucks are both more expensive and of more poor quality compared to SEMAPA, but some people do not have any other options than buying this water. Sometimes as much as 10 % of a household's total income goes to payments related to the water (Ledo 2009).

1.1.1 Rio Rocha

Rio Rocha is the city's only river that flows through the entire town to the southwest. During the rainy season several creeks caused by melting snow and rain, connects with the Rio Rocha and contributes to its water (Aguilar and Valdivia 2013)(Ledo 2009). During the dry season the water in the Rio Rocha mainly consists of water from sewers, industries, hospitals, tanneries, car washing and other industries that use chemicals as soap and oil in their manufacturing process. Thus, the degree of pollution is higher in the dry season than the rainy season because of variations in the flow (Aguilar and Valdivia 2013).

In recent studies from the university San Simon in Cochabamba, the water quality of the Rio Rocha is described as very poor. Identified sources of pollutants are sewage (both municipal and private networks), industrial wastewater and run off from landfills. These sources in combination with other human activities are the primary sources for both point and diffuse discharges into the Rio Rocha (Iriarte, Coronado and Mercado 2013). The degree of pollution in the Rio Rocha is a risk factor when it comes to the transfer of diseases, including various forms of cancer. Accumulation of heavy metals in body tissues and organs is for example a cancerogenic factor over time (Aguilar and Valdivia 2013). The child mortality in Bolivia is very high and one in twenty kids dies before they reaches the age of six. One of the main factors causing this is the high concentration of contaminators and bacteria's in the water (Schultz 2009). This water is then transferred to humans by inadequately treated drinking water and contaminated food.

Along the river bank of the Rio Rocha farmers use the contaminated water to irrigate their crops, especially vegetables. This reduces in long term the soil fertility which may have consequences in terms of reduced harvests of key crops such as vegetables, grains and legumes. Cattles consume the contaminated water and inhaling bad smells from the river. Irrigation with wastewater increases the risk for diseases associated with nematode and fecal bacterias for both consumers and farmers. The most common diseases caused by pathogens found in water of the River Rocha is diarrhea, typhoid, cholera, salmonellosis, infectious hepatitis, gastroenteritis, meninitis, respiratory infections, amoebic dysentery and intenstinal disorders (Aguilar and Valdivia 2013).

1.2 Problem description

In the report by Iriarte et al (2013) it is concluded that it is obvious that Sacaba do not have good enough wastewater treatment for the district's approximately 179 847 residents. It's also problematic that wastewater treatment not has been improved for the municipalities close to the river bank of Rio Rocha even though the population has increased (Iriarte, Coronado and Mercado 2013).

As the study by Iriarte et al demonstrates the lack of good wastewater treatment in the majority of Cochabamba's municipalities, it is both interesting and meaningful for this master thesis to evaluate and investigate possible ways to improve wastewater treatment in urban neighborhood. The idea was to identify a small residential area in which wastewater currently contaminated the river, and use this neighborhood as a case study. The idea was that this case study could be used to exemplify how wastewater treatment is managed in this kind of urban areas. Since the chosen area is a very typical Bolivian neighborhood it is likely that the results from this area had been the same if another similar area had been studied. The results from this study could hopefully be utilized in future cases in the same area.

1.2.1 Aim

The aim of this master thesis is to evaluate and suggest improvements for the wastewater treatment in a neighborhood, organized as a cooperative, in the municipality of Sacaba. The neighborhood is part of the metropolitan area of Cochabamba located approximately 8 km downstream Sacaba along the river Rio Rocha.

1.2.2 Research question

The thesis aims to answer the following questions:

- How efficient is the current treatment?
- How did the neighborhood implement the wastewater treatment and how do they maintain it?
- What type of improvements can be done?
- How is the Rocha River influenced by this neighborhood and other similar residential areas?

1.2.3 Delimitations

The proposed improvements will only focus on simple wastewater treatments options, such as septic systems and other easily constructed solutions that are commonly used in developing countries. The proposed improvements will only be theoretical and only a few solutions will be included in the analysis, since including all kind of possible solutions and systems is beyond the scope for this thesis. The included solutions are solutions that are possible to implement in the studied neighborhood which means that solutions for both rural areas and for larger cities not will in the analysis.

1.3 Method

The study is constructed as a single-case study, with a mixed approach, of the chosen neighborhood and their wastewater treatment system. The method for data collection will be literature searches, interviews and field work. To decide which kind of improvement that is optimal for this area's wastewater treatment plant Multi-Criteria Analysis (MCA) will be used to describe the various proposals advantages and disadvantages. The criteria for the MCA-analysis will be based on interviews and observations from the neighborhood. From these criteria, a matrix will be constructed where the different solutions are given a score. The matrix will give a good overview and ranking of the potential improvements.

2. Background

The availability of water and sanitation has increased in Bolivia in the last decades. However, the supply is still inadequate in many parts of the country, and there is a large difference between rural and urban areas. In 2005, 40.5% of Cochabamba's population had access to basic sanitation, which is an increase of eight percentage points since 1992. Nationally throughout Bolivia, the average value of 43.5%, this means that sanitation supply in Cochabamba is relatively low. The aim is to achieve coverage of 64 % by 2015, which means that further efforts are needed (Barcarreza et al 2007).

Figure 2. Cochabamba on a Bolivia-map (Bolivia Contact 2014).

2.1 Cochabamba

SEMAPA (Servivio Municipal de Agua Potable) is the municipal water system in Cochabamba City, but the service reaches far from all. Their system is also undersized, and the risk of contamination is high because of poorly constructed pipes. It is mainly the northern parts of Cochabamba who get their water supply of SEMAPA. As the city has grown rapidly in recent year's water shortage is a problem, especially in southern Cochabamba where SEMAPA's services are insufficient. The situation is the same for the wastewater, since the SEMAPA treatment plant mainly treat water from northern Cochabamba.

Since SEMAPA's wastewater treatment plant has a too small size compared to the increased inflow of water, the water passing there may therefore not get enough treatment (Helgegren and Siltberg 2012). In southern Cochabamba there is no connection to SEMAPA, and adequate treatment facilities are missing in many places. This means that raw sewage is released directly into the environment in many places (Mercado 2012).

The department of Cochabamba consists of 45 municipalities and 16 provinces. Many of these municipalities are organized in the same way as SEMAPA. Also in these municipalities water supply problems are common (Helgegren and Siltberg 2012). In those places where there is not possible to join the municipal network, water issues are often organized by the water committee in the local OTB (Organizaciones Territoriales de Base) organizations (Helgegren and Siltberg 2012). Another possibility is also to organize a neighborhood into a water cooperative. In the cooperative the members themselves are responsible to pay for all the costs related to their sewer system and drinking water. As the amount of independent water systems increase, the demand of ground water of good quality also increases. Unfortunately, an increased amount of independent water systems usually give a greater contamination of the groundwater, with health problems as a result to this (Nickson 2002).

2.1.1 Sacaba and the studied area

Sacaba is located east of Cochabamba and is the second largest city in the department of Cochabamba and the municipal water system in Sacaba is obtained from EMAPAS.

EMAPAS has plans to construct two wastewater treatment plants for the entire municipality of Sacaba but the area of land that is planned to be used is slightly too small for everything to fit it in. EMAPAS already have funding and permission for this treatment plant, but the society next to Sacaba oppose because they do not want the treatment plant near their residential area. This conflict has been going on for about 2 years[1].

The neighborhood chosen for this study is located between Cochabamba and the centre of Sacaba and became a residential area in the 1970's. The location of the area is shown in figure 3. From the beginning there were only about two streets and 3-4 houses. Those who lived there were mainly teachers and the area was populated very quickly[2,3,4]. There was no water and no light, but there were natural springs with very good and crystalline water that was used as a water source. In the beginning, some of the houses used their own wells, but as the population in the area grew, neighbours decided to get together and drilled the first common well. All the neighbours helped out and as the population continued to grow, two more wells were drilled. This led to the neighborhood deciding to organize themselves as a water cooperative in the early 1980s.

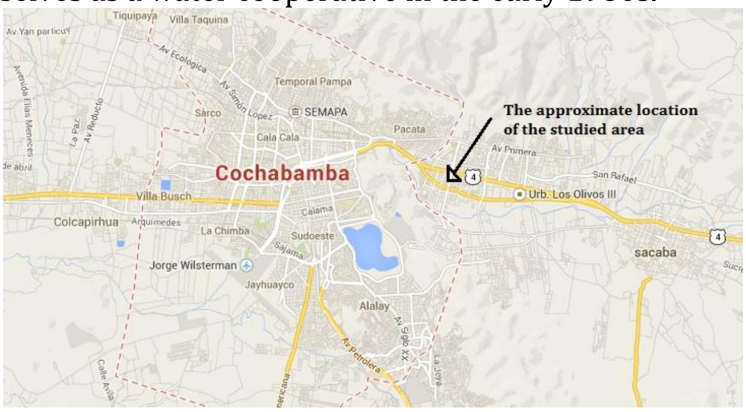

Figure 3. The studied area is located between Cochabamba and Sacaba (Google maps 2014).

[1] Person number 3, interview 1
[2] Ibid.
[3] Person number 1
[4] Person number 2, interview 2

2.1.2 Description of the waste water treatment system

273 families are connected to the cooperative's service in the study area. The members are divided in plan A and plan B, which means that there are two elevated storage tanks and two septic tanks for wastewater. Not every family has both the sewage system and the drinking water system from the cooperative. In Plan B there are some families that have their sewage system connected to the municipal company EMAPAS and in plan A, there are some that only have drinking water. The cooperative started with plan A, but as the population grew this was not enough, so plan B was constructed. There are two wells used for drinking water, and these are 100 meters deep. Water is pumped from the wells into two elevated storage tanks and is then distributed[5].

Plan A was constructed in 1983 and has about 90 households connected. Plan A had 25 households connected from the beginning and when more people settled in the area also more households was connected[6]. Plan B was constructed in 1988 but this septic tank stopped working in 2004, which means that all waste water from Plan B currently goes directly into the river. This septic tank is completely covered underground and a possible reason for why it collapsed is erosion and dumping of construction waste Plan B has 180 households connected and the reason for that plan B has more households than Plan A is because of the location.

The distance between septic tanks are 120 meters and both of the septic tanks are 7 m long x 4 m wide x 2 m deep in size with is equal to 56 m^3. Each septic tank has three chambers and there are two walls separating them from each another. In the beginning was Plan A connected to a filter made by stone and coal, but this only worked for three years before it collapsed. The septic tank for plan A was emptied of liquid 15 years ago, but emptying of sediment has never taken place and no maintenance is done for the moment. The septic tank for Plan A has a lid. Flooding occurs during the rainy season and many of the households get down rainwater in their water systems[7].

Both of the septic tanks are composed of cement and steel. The construction of the septic tanks was made by a civil engineer who lived in the area, who offered to create a design because he had the knowledge. He contributed with his knowledge for free, and the system that was constructed could be used by a maximum of 100 families. It took almost two years from the planning of the septic tank began until the tank was finished. The process was not difficult, according to interviewee 1, and everyone in the area helped out with the work[8]. There are no drawings or written material that describes how the tanks were constructed[9].

[5] Meeting at the cooperative, 2nd of July 2013
[6] Ibid.
[7] Ibid.
[8] Person number 1, interview
[9] Meeting at the cooperative, 2nd of July 2013

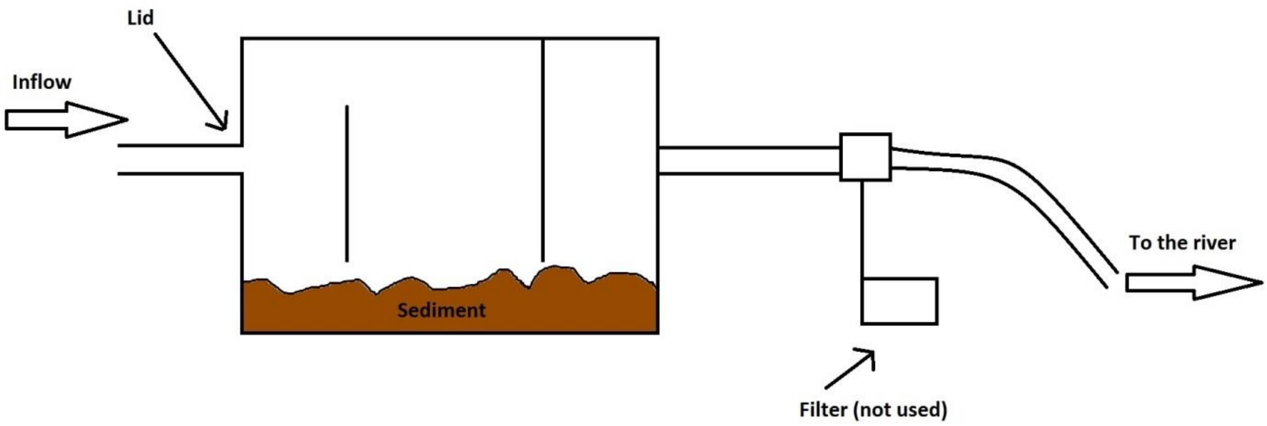

Figure 4. Illustration of the septic tank.

2.2 Work by local organizations

In Cochabamba there are a couple of different organizations that are working with finding new options for wastewater treatment. The following section will present two of them.

2.2.1 Aguatuya

Aguatuya is an organization that works to promote local initiatives for water and sanitation in urban areas. The idea is that as the population of Cochabamba grows there will be more beneficial if each neighborhood has its own wastewater treatment plant rather than that there is only a facility for the whole metropolitan area (Aguatuya 2013). This will be both safer and more environmentally friendly because if the treatment for any reason would be incomplete the consequences will be less than if an accident occurs at a larger facility with more wastewater in. The technique that Aguatuya uses is a combination of anaerobic bioreactors, biofilters and sub-surface flow constructed wetland with horizontal flow. This technique treats the water through natural processes without the need for either high energy costs or chemicals (Aguatuya 2013). The steps in the process are shown in table 1. For a map over the process, se appendix 6.

Table 1. Wastewater treatment by Aguatuya (Aguatuya 2011).

1	Chamber of bars	In the beginning of the treatment system, there will be removal of solids larger than 2.5 centimeters.
2	Degreasing	Removal of fatty material by suspension in water since the fat will be on top of the water.
3	Anaerobic bioreactor	Removal of organics in an upflow anaerobic bioreactor by anaerobic processes.
4	Biofilter A and B	SSF- wetlands with horizontal flow for removal of organic nutrients like potassium and nitrogen. Wetland A is made of gravel and wetland B from coarse sand.
5	Lagoon polish	Removal of organic and inorganic trace elements from the biofilters.
6	Sludge drying bed	Mechanical removal of the organic sludge in the bioreactor.

2.2.2 Fundacion Abril

Fundacion Abril is an organization based in Cochabamba with a vision to work for a society where all citizens have access to water. Based on topographical studies have they made a proposal for a wastewater treatment system consisting of an up flow anaerobic reactor. Other components that are planned to be part of the treatment system is chamber of bars, grit chamber, flow meter, distribution box, bed-do dry sludge and gravel filters (El Chiwanku 2013).

3. Theory

This chapter aims to theoretically present the technologies that are of relevance to this thesis. The focus will be on describing the various water parameters and wastewater treatment solutions. Focus will be on simple treatment solutions that actually can be implemented in a developing country.

3.1 An introduction to water sampling

Untreated wastewater is a serious problem in many areas in the world with diseases and infant mortality as a result (Schultz 2009). The following section will describe some common parameters that are used as indicators to describe and evaluate water quality.

3.1.1 Turbidity

Turbidity is a very useful indicator of water quality since it is a measurement of the amount suspended and dissolved particles in a water sample. Turbidity can be seen as a measurement of the cloudiness of the water. Suspended particles absorb heat from sunlight, which makes the water warmer with a reduced concentration of oxygen since oxygen is more soluble in cold water. This will disturb the natural balance of organisms in the water because some organisms cannot survive in warmer waters, while others reproduce more quickly. The suspended material may be clay, mud, organic and non-organic compounds, plankton and microorganisms. Turbidity is measured in Nephelometric Turbidity Units (NTU), and the measurements are performed with a nephelometer. The technique is based on measuring the amount of light reflected from the instrument which is related to the amount of particles present in the sample (Bartram and Ballance 1996).

3.1.2 Suspended solids

Total suspended solids are the amount of dry material that is removed from a water sample with a known volume. The material is separated from the water using a filter and is then allowed to dry. To make this type of analysis possible to repeat with comparable results, it is important to note the type of filter used, and the time and temperature for the drying procedure (Bartram and Ballance 1996).

3.1.3 BOD

Biochemical oxygen demand (BOD) is a measure of how much oxygen organisms consume in their metabolism when organic material is biochemically degraded in wastewater or natural water. The information from a BOD measurement is very useful when designing a new wastewater treatment plant. The standard method for the analysis starts with incubation in the dark at 20° C for a specific time, typically five days. However, it is impossible to recreate the natural water conditions in the laboratory when it comes to temperature, biological population, water movement, sunlight and oxygen content, which must be taken into account when the results are interpreted (Bartram and Ballance 1996).

3.1.4 COD

COD stands for Chemical Oxygen Demand and is a measure of the amount of oxygen consumed by organic material in their oxidation process in a water sample. In this way, the organic material in a water sample is determined which makes the method suitable for the characterization of water, sewage and effluents. It is important that exactly the same technique is used if samples should be able to be compared to each other, since the amount of oxidized material is dependent of the properties of oxidizing agent that is used, a common one is potassium dichromate solution (Bartram and Ballance 1996).

3.1.5 Colour

Colour can either be measured as true colour or apparent colour. Apparent colour is the colour that is observed by a human eye, and can for example be caused by suspended particles. Since there are other factors that influence the apparent colour, like the colour of the sea bottom and the colour of the sky, this method is not preferable in research (University of Florida n.d)

For true colour measurements the water needs to be filtrated before analysis to remove suspended particles. Then, the colour of the water is compared to a scale, usually a platinum-cobalt scale (UPC) is used. The UPC-scale consists of 1000 colours. A very clear water has around 10 UPC, but more dark water will have 500 UPC or higher (University of Florida n.d).

3.1.6 Fecal coliforms

Fecal coliforms are also called thermo tolerant coliforms and the presence of this one almost always indicate faecal contamination, even if all organisms included in this group not are of faecal origin. Approximately 95 % of the thermo tolerant coliforms detected in water is the gut organism Escherichia coli and therefore the presence of thermo tolerant coliforms are good evidence that the water is contaminated with faeces (Bartram and Ballance 1996).

This kind of coliforms grows at 44-44.5° C and ferment lactose to produce acid and gas. When grown in the laboratory a lactose-containing media is used at the given temperature. The organisms are then identified by the production of acid and gas (Bartram and Ballance 1996).

If an unusually high amount of coliforms are obtained, it should be considered that the high levels maybe are caused by other types of thermo tolerant coliforms than E. coli. This happens especially in nutrient-rich environments (Bartram and Ballance 1996).

3.1.7 pH

For pH-measurements three different techniques are commonly used; electronic meters, pH indicator paper and liquid colorimetric indicators. If possible, it’s always to prefer to make the pH-measurements at the place where the samples are collected (Bartram and Ballance 1996)

3.1.8 Conductivity

Conductivity is a measure of water's ability to conduct electrical current, and the unit used is microsiemens per centimeter (µS/cm). Since the conductivity changes with storage time, it is preferable that the conductivity measurements are made in the field. Conductivity is a good indicator of a high ion concentration in the sample (Bartram and Ballance 1996)

Table 2. The maximums allowable limits for liquid discharges in Bolivia (CASA 2013)

BOD	80 mgO_2/L
Coliforms	1000 UFC/100 mL
COD	250 mgO_2/L
pH	6-9
Suspended solids	60 mg/L
Sulphides	2 mgS/L

3.2 Wastewater treatment alternatives

The following section aims to present some primary- and secondary wastewater treatment solutions.

3.2.1 Septic tank – primary treatment

A septic tank is usually the first step in a household treatment system that treats wastewater and household water (USAID 2008). A septic system at household level usually consists of a septic tank, a distribution box and drain field (EPA 1999). In the septic tank the inflow of wastewater will sediment, which means that heavier particles will sink to the bottom of the tank where they are decomposed by microorganisms that are naturally present in the water (USAID 2008). Other components in the wastewater like grease, oil, fat and digested solids forms a scum layer on the water's surface which means that the treated wastewater is between the settled sediment and scum layer (EPA 1999) . Inside the septic tank there are baffles that divide the tank into different parts and help the scum layer to remain in the first part while the liquid can pass to the next. A minimum of two sections is required and the first section should be at least 50% of the total length. If there are only two sections in total, the first section should be 2/3 of the total length (Tilley et al 2008). It is also common that an effluent filter is used together with the baffles to retain as much solid material as possible in the tank's first section (USAID 2008). A T- shaped outlet pipe in the last section also helps to reduce the risk that scum and solids leaves the tank (Tilley et al 2008).

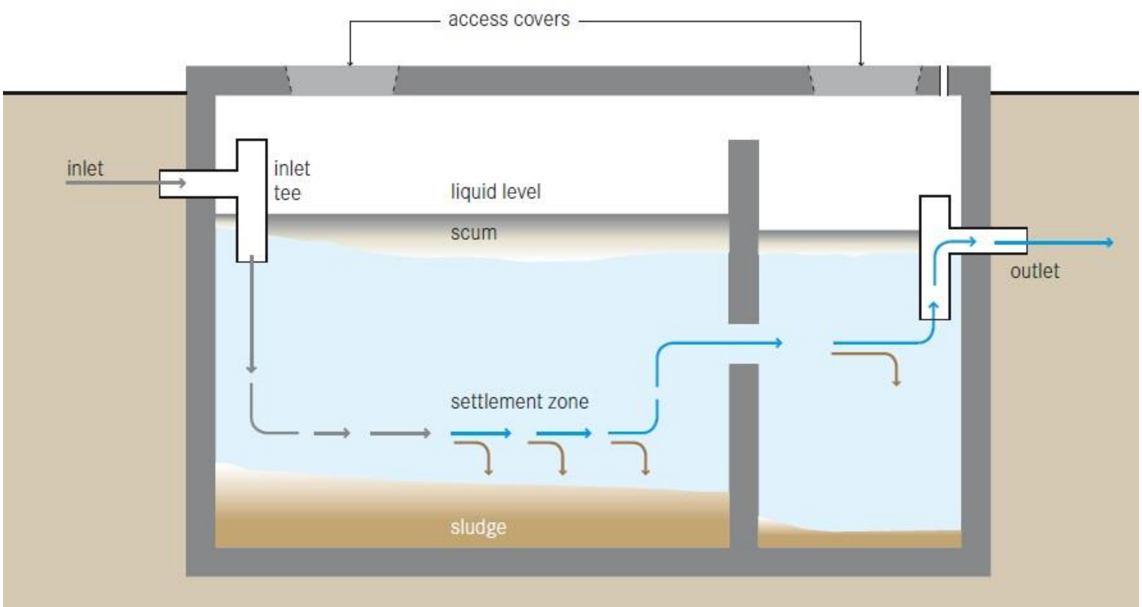

Figure 5. The construction of the septic tank (Tilley et al 2008)

A septic tank is usually made of concrete, plastic, fiberglass or polyethylene but never of wood or steel. The important thing is that the material is waterproof and long-lasting, since wastewater otherwise might leak into the groundwater and contaminate it (USAID 2008) (EPA 1999). It is also important that the tank has some kind of ventilation system since hydrogen sulfide is formed during the decomposition process, which has a smell similar to rotten eggs. The place where the septic tank is placed should also be easily accessible so maintenance easily can be done, and the distance to the nearest well should be at least 25 meters to avoid contamination. An improper design can lead to contamination of groundwater and nearby wells, and these designs are still accepted to some extent in developing countries (USAID 2008).

To make the septic tank function optimally, it is important that the sediment is removed when the sediment volume reaches 1/3 of the tank's total volume. The tank usually needs to be emptied every 3-5 years depending on the size and how much it is used (USAID 2008). However, the tank should be inspected by a technician annually to determine the current status (Tilley et al 2008). If this maintenance is not done, the wastewater will pass through the tank without being treated and this will contaminate the environment. To make the sedimentation process in the septic tank effective, it is important that the tank is large enough to keep the incoming water in the tank long enough (USAID 2008). A residence time of about 48 hours is needed to achieve complete treatment (Tilley et al 2008). A common used estimation is that the septic tank should have a volume that is 2.5 times greater than the maximum daily flow of wastewater. If water consumption data not is available, an average of 150 liters/person/day and 5 persons per household are used for calculations (USAID 2008).

Excessive use of detergents and household chemicals can harm the bacteria in the septic tank and oil and grease from cooking can clog the pipes. It is also important to not flush cigarette butts, diapers, napkins and similar things into the toilet. Flow of rainwater should be kept away from the septic tank as this may reduce the effectiveness (USAID 2008).

Generally, a septic tank will remove 50% solids, 40% BOD and 1 -log reduction of E. coli, but the efficiency is largely dependent on the maintenance and the climate. Septic tanks can be installed in any type of climate but the tank will be less effective in a colder climate. Disadvantages with the septic tank are that the reduction of pathogens, solids and organics are low and that the effluent and sludge require some type of secondary treatment (Tilley et al 2008).

3.2.2 Anaerobic Baffled Reactors (ABR) – primary treatment

An Anaerobic Baffled Reactor (ABR) is an improved septic tank where several baffles inside the tank create a longer contact time between the biomass and the wastewater, which gives a more efficient treatment. In the first chamber of the reactor most of the seattleable solids are removed, and this part corresponds usually to about 50% of the total volume. The BOD reduction is around 90 %, which is a significantly higher reduction than for a classical septic tank. As in a classical septic tank desludging is required, about every 2-3 years is usually enough. The hydraulic retention time (HRT) should be 48 to 72 hours to achieve the best efficiency of the treatment. The technique is suitable either for a single household or for a group of houses, but one requirement is that the outflow of waste water is relatively constant and around 2000 - 200 000 L/day. The technique is not suitable where the water table is high because the risk of ground water contamination (Tilley et al 2008).

An ABR should not be installed where a treatment system is needed rapidly because after the installation it will take several months before the tank operates at full capacity. The reason for the long start-up time is because it takes time for the anaerobic digestion process to get started. Sludge with bacteria can be introduced into the reactor at start-up to reduce the time. An ABR has a long lifetime and can usually be both built and repaired with locally available materials. The reduction of pathogens is unfortunately low and secondary treatment is needed after an ABR (Tilley et al 2008).

3.2.3 Anaerobic Filter – primary treatment

The technique anaerobic filter consists of a septic tank followed by one or more chambers with filters in. When waste water flows through these filter particles are trapped and organic matter is broken down by biomass. Materials commonly used for this type of filters are gravel, rock, ash or plastic pieces. A good filter material contributes with a large area compared to the total tank volume as this provides a larger contact area. Hydraulic retention time (HRT) should be between 0.5 - 1.5 days and the maximum flow per area unit should be around 2.8 m/d (Tilley et al 2008).

Anaerobic filters are recommended for the same type of households as the ABR and the anaerobic filter also need a start-up time because of the anaerobic digestion process. During the start-up process, active bacteria must be added to the filter and the flow can then be increased gradually and reaches its full capacity in 6-9 months. An anaerobic filter can be constructed both under and above the ground depending on what is best suited for that particular area. The outflow effluent from the filter can have a strong odour and should be positioned so that it does not disturb those who live in the area. The filter also needs to be vented to prevent hazardous gases from being released. The filter must be cleaned regularly to avoid that solids clog the pores (Tilley et al 2008).

Reduction of the BOD-concentration is usually between 50-80 %, but can under optimum conditions be as high as 90%. Removal of nitrogen is unfortunately not so high and usually around 15% (Tilley et al 2008).

3.2.4 Anaerobic biogas reactor – primary treatment

An anaerobic bioreactor is a chamber where wastewater is treated and biogas is produced. It can be located either under or above the ground. When the wastewater enters the reactor are gases produced through fermentation processes. These gases are then collected in the top of the reactor. The reactor can be used almost everywhere a septic tank is used, the benefits from this one is that it also captures energy. Since it is located underground it's suitable for populated areas where it lives many people and the space is a limit. Since it is a safety risk with the gas inside the tank, the construction needs to be tight to prevent leakage. The reactor needs to be maintained and emptied every 6-10 years. The maintenance is cheap and it's also a non-expensive construction to build (Tilley et al 2008).

3.2.5 Soak pit – secondary treatment

A soak pit (also known as soakaway or leach pit) is a construction placed under the ground where greywater and blackwater treated by eg a septic tank is allowed to slowly infiltrate into the soil and go back to the ground water. When the water penetrates the ground, the small particles will be filtered out by the soil and organic matter will be degraded by naturally occurring microorganisms. A soak pit can either be constructed with porous walls without any filling or constructed without walls, but filled with rock and gravel to avoid that the space collapses. For both of the design types, one layer of sand and grit needs to be spread over the bottom of the chamber to facilitate the water flow. A soak pit must be located at least 1.5 meters above the ground water level and the soak pit is usually 1.5 - 4 m deep. It should also be placed with a minimum of 30 meters from drinking water sources (Tilley et al 2008).

The technique is best suited to soils with good absorbency and therefore is not clay or rocky soils suited. The technique is not suitable in areas where floods are common or where the ground water level is high. A soak pit is very suitable for rural and periurban settlements, since it is covered under the ground it will not use a lot of space or spread any unpleasant smell. A soak pit usually lasts for 3-5 years, and then it will be clogged by biomass particles and maintains is required (Tilley et al 2008).

3.2.6 Leach field – secondary treatment

A leach field (also called a drainage field) is a network of pipes that allow the water treated by e.g. a septic tank to be infiltrated back to the soil. The pipes are placed underground in trenches that are 0.3 - 1.5 m deep and 0.3 - 1 m wide. The pipe is positioned in the middle of the trench with a bed of stone both under and above. On top of the construction there is also a protective layer of geotextile to prevent small particles from clogging the pipes. The wastewater is distributed to the system from a distribution box that is controlled with a timer so that an adequate amount of water is released about 3-4 times per day. The pipes should be placed about 15 cm from the surface to prevent leakage. The trenches should not be longer than 20 meters and should be placed 1-2 meter from each other. The distance to the nearest drinking water source should be at least 30 meters (Tilley et al 2008).

A leach field requires a large area of land with good absorptive properties. Because the technology is covered under the ground are the health risk are very small. Plants with deep roots should be kept away from the area, otherwise the equipment might be destroyed. A good constructed leach field requires minimal maintenance, but if the system's efficiency declines, it is important that it is repaired as soon as possible. The design has a lifespan of about 20 years, and both operating and investment costs are relatively low. However, the leach field requires a professional design and it can also be difficult to locally find all the kind of materials needed for the construction. The design can also have a negative impact on the environment and the groundwater (Tilley et al 2008).

3.2.7 Constructed Wetland Horizontal Subsurface Flow– secondary treatment

Constructed wetland is a purification method using aquatic plants and the surrounding soil to purify water with help from biological processes. The horizontal subsurface flow constructed wetland consists of a watertight channel in the ground that is filled with gravel where aquatic plants are grown. Wastewater flows horizontally through the construction and the plants roots will be a part of the treatment process in which unwanted substances are broken down by microorganisms (Davis 1994).

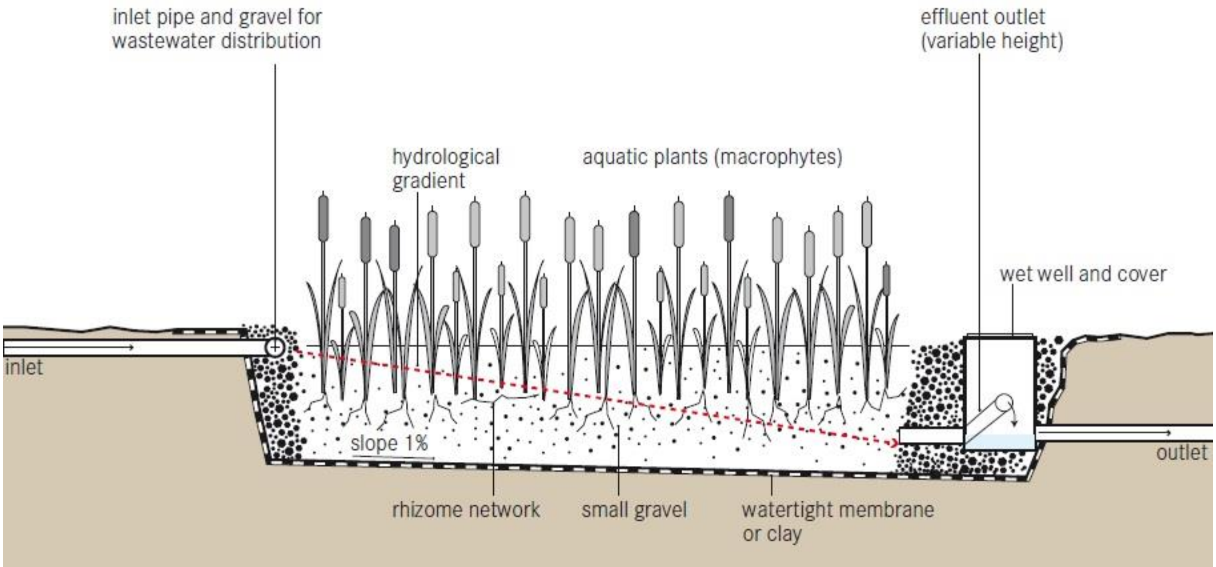

Figure 6. The construction of a constructed wetland (Tilley et al 2008)

Compared to many other secondary treatments, the method is cheap in installation, operation and maintenance. The plants can be used for example as animal feed and the estimated surface area needed is about 1 m^2/person (Franken 2007). The constructed wetland has a high reduction in pathogens, BOD and suspended solids. A good pre-treatment is required since clogging is a common problem. The facility can be built with material that is possible to find locally but for the design help from experts is necessary (Tilley et al 2008).

4. Method

The study is constructed as a case study. The method for data collection was literature search, interviews and an experimental part. To answer the question about what kind of waste water treatment the neighborhood have, how it was implemented and how it is maintained, mainly interviews with those who live in the area and with key people in the cooperative will be done. This will be complemented with site visits and observations in order to get a good perspective of the situation. To find information about how efficient the treatment is water sampling will be done before and after the treatment, in order to evaluate the efficiency. The parameters that will be measured are fecal coliforms, total and suspended solids, sulfides, BOD, COD and flow rates. After the first sampling the septic tank will be emptied, and then the same measurement will be done again. The reason for doing this is to evaluate how much more efficient the treatment is when the septic tank is maintained. The efficiency of different waste water treatment systems will also be described and evaluated in the theory chapter.

To be able to describe how the Rio Rocha is influenced by this neighborhood and other similar places, a sampling from the river will be done at two different sampling points, totally three times with two weeks between every sampling. The parameters that will be measured are fecal coliforms, BOD, COD, color, turbidity and flow rate. This sampling session will also describe the differences between the dry and rainy season. Since the University San Simon in Cochabamba has done this type of sampling since the end of March 2013, the collected data will in total be between March 2013 to July 2013.

4.1 Case study description

The study is constructed as a single-case study with a mixed approach, of the neighborhood and their wastewater treatment system. For a part of the study, a qualitative research design is chosen since it is a suitable design to use when real life situations are studied (Yin 2009) (Jonker and Pennink 2009) (Suddaby 2006). This research design does not have a fixed design, instead the design can be seen as flexible and can be adjusted during each step of the process (Maxwell 2012).

The reason why this neighborhood was chosen is because it represent a very typical middle class neighborhood in Cochabamba were both money and knowledge is available, hence these are not direct barriers. Cochabamba has a long tradition of community-based systems and therefore it is very suitable to study a cooperative since it will give a good perspective of the situation in many community-based organizations. In a qualitative study, the presentation of data is sometimes a bit difficult, since it is important to clarify what of the information that is fact and what of the information that is the researcher's own opinions (Jonker and Pennink 2009). One way to make the study more trustworthy is to include quantitative data as well, since it gives a better perspective of the situation (Jonker and Pennink 2009) (Bryman 1988) (Eisenhardt and Graebner 1989). The quantitative data in this study will mainly be data of measurable character, like water parameters.

Table 3 shows how the case study is constructed and what kind of information that is desirable.

Table 3. Description over how the research question is studied, What data are relevant, how to collect this data and how to do the analysis.

Research question	Data needed	Data collection	Data analysis
How efficient is the treatment?	Quantitative data about all measured water parameters.	Sampling sessions from the wastewater treatment.	Water analysis at the university.
How did the neighborhood implement and maintain the wastewater treatment?	Qualitative data.	Qualitative in-depth interviews, site-visits, observations.	Text analysis by looking for key words frequently brought up.
What type of improvements can be done?	Qualitative data.	Literature study. Qualitative in-depth interviews, snowballing, site-visits, observations.	MCA-analysis.
How is the Rio Rocha influenced by the neighborhood and other similar places?	Quantitative data about all measured water parameters.	Literature and sampling sessions from the river.	Water analysis at the university.

The aim of this study is also to gather quantitative data about the area and their wastewater treatment system. The qualitative data will play an important role when it comes to suggest theoretical improvements for the system since different kind of systems will be suitable depending on what kind of qualitative data that is found. The qualitative data will for example describe the cooperatives organisation, their knowledge about water and sanitation, and their interpersonal skills.

4.1.1 Data collection

During the study the persons who are interviewed will point out interesting documents and key peoples that are relevant for this research, a method also known as snowballing. The qualitative data will mainly be collected through interviews with the neighbours, while the qualitative data such as information about the wastewater treatment system will be collected from key-people.

4.2 Literature study

To be able to suggest a new wastewater treatment plant for the neighborhood or suggest improvements for the current system, knowledge about various wastewater treatment systems is required. The literature study will primarily focus on finding information about different wastewater treatment options in both articles and reports to gather useful information that will form the basis for the MCA-analysis. The improvements will mainly focus on low cost solutions that actually can be implemented in the area without being too expensive. The literature review is also needed to evaluate the current system.

4.3 Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is a useful method to compare the pros and cons of different types of projects, making these quantifiable (Gamper, Thöni and Weck-

Hannemann 2006). This means that a defined object with a defined goal can find its best solution if a matrix with a special scoring system is constructed. A number of criteria are selected and these are then weighted and given various weights, depending on how important the criteria is considered to be for the specific situation. The higher weight score a certain criterion is assigned, the more important it is for the specific situation.

After the criteria have been chosen, a number of possible solutions to the targeted problem are defined. These solutions are then given points with respect to how well they fulfil a particular criterion. A high point thus implies that the suggested solution has great potential to meet the criteria while a low point means that the chance is not that high. Finally all weight points are multiplied with all the specific points for the solution, and this will form the matrix. Each solution finally gets a total score and this makes it easy to compare the different solutions with each other and in that way the best solution to the problem is found (Gamper, Thöni and Weck-Hannemann 2006).

Based on the definition above, the MCA-analysis is considered as an appropriate analytical tool in order to suggest which wastewater treatment system that could be most suited for the neighborhood. The ability to weight the different criteria is good since this makes it easy to adjust the evaluation of wastewater treatment alternatives to the situation in this area and their specific needs. The scoring of the different systems that finally will give a total score also gives a good overview of how the analysis has been done. This will make it easy for the members of the cooperative to follow how the analysis was performed, which hopefully will create an understanding of how the improved proposal has been developed.

If the cooperative consider that their needs are different than the criteria and weight scores presented in the MCA-matrix it is easy for them to change these parameters. The idea is that this master thesis in the first place will put points on all of the solutions presented. Then the cooperative by themselves can put weight points on the criteria that meet their needs and in that way find the optimal solution.

5. Description of field work

This chapter aims to describe how the field work in the neighborhood and in the Rio Rocha was performed.

5.1 Sampling points

For the sampling in the neighborhood, four different sampling points were chosen; inflow 1 to the septic tank A, inflow 2 to the septic tank A, outflow plan A and outflow plan B. Figure 7 shows a map over the locations of the sampling points. The last sampling point, outflow plan B, was used to comparison with outflow A to see if there were any differences between these to. After the first sampling session the septic tank was emptied, and two weeks after the same measurement were done again. The reason for doing this was to evaluate how much more efficient the treatment was after maintenance.

All the sampling was done in the morning before 12.00. Flow rates were however measured at different times over the day in order to be able to find the peak for the flow. The emptying of the septic tank were performed together with ServiMaster, a company specialized in emptying septic tanks.

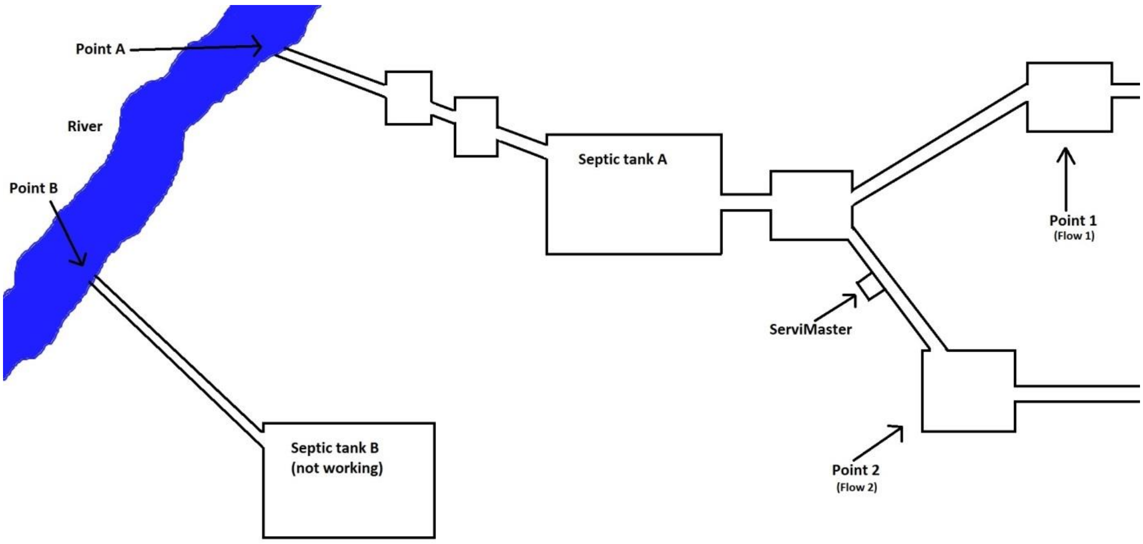

Figure 7. Map over the sampling points.

5.1.1 Sampling session 1 – 15 july

At the first sampling session the water at point 1 was about one meter deep. The water samples smelled incredibly bad and it was large solids in the water. At this sampling point, the water flow was very slow and the water was very sticky and thick. At point 2 the water was also about one meter deep. Here the water was somewhat clearer than at point 1, but the flow was also very slowly and the water smelled terrible.

At the outflow A the water flows at a steady rate through a pipe to the river, and the smell from the river is really bad. At the outflow B is the outflow of water is noticeably faster than at the outflow A, and the smell here is also really bad.

Picture 1. Point 1 is located in the left corner in this picture. To the right it is almost possible to se the entrance to the septic tank. Point 2 is located to the right of the septic tank.

Picture 2. Outflow to the river from plan A.

Picture 3. Outflow from plan B.

5.1.2 Maintenance with ServiMaster 17 july

When emptying the tank with ServiMaster some problems were discovered. Since the tank only had a lid at the entrance it was only possible to remove liquid from the tank but no sediment or solids. During ServiMasters work the water level dropped significantly at both point 1 and point 2. However, the water level got back to its normal state until the afternoon. ServiMaster emptied the tank on a total of 15 m^3 of liquid.

Picture 4. Maintenance with ServiMaster. The entrance to the septic tank is located to the left in the picture and point 1 is located to the right.

5.1.3 Sampling session 2 – 31 july

At the sampling session 2, the water level at point 1 and point 2 had become extremely low. At point 1 the flow consisted of only of a thin trickle of water with a depth of only a few centimetres. At point 2 the water was slightly deeper, about 1 decimetre. This change was due to that the technician had removed some kind of blocking object in a pipe that is connected to point 1 and point 2, which then changed the water level. The smell was still disgusting and the water at both sampling points was sticky and contained solids. At outflow A and outflow B the observations were the same as at sampling session 1.

Picture 5. Extremely low water level at point 1.

Picture 6. Waters samples from point 2.

5.2 Sampling from the Rio Rocha

To be able to describe the contamination of the river and to demonstrate differences between the dry and the rainy season, samples were taken from two different locations in the river. The samples were taken totally three times with two week in between. The University San Simon in Cochabamba has performed this type of sampling since the end of March 2013, so data collected between March 2013 to July 2013 will be available in the result section.

Figure 8. The location of the sampling points (Aguilar and Valdivia 2013).

5.2.1 Puente de servicio de camino – point 1

Puente de servicio de camino is the name of the sampling location located closest to Cochabamba. Here, the water is very dirty and the smell from the river is intense. Close to the river is a car wash located, and its water is contaminating the river. There is also an outflow of wastewater nearby. Since hens are walking around close to the water it is very likely that their faeces are present in the water.

Picture 7. Puente de servicio de camino

Picture 8. Car wash close to the river at puente de servicio de camino

5.2.2 Puente huayllni – point 2

Puente huayllni is located closer to Sacaba and more faraway from Cochabamba. Since the water has not been transported through Cochabamba yet, the water here is much clearer and less contaminated. Both the flow and the depth of the water is smaller compared to the other sampling point. Small pink flowers and green leaves are growing in the water and in the area there are also a clothes washing facility. There is also a football field nearby. At one of the sampling sessions there is a small dead animal in the water, but it’s not possible to identify the type.

Picture 9. Puente huayllni

5.3 Sample analysis

The parameters that were measured were fecal coliforms, total and suspended solids, sulfides, BOD, COD, color, conductivity, turbidity, pH and flow rates. All samplings analysis was done by CASA, which is the center of water responsible for analysis at the university.

Table 4. The methods used for analysis at CASA – Universidad Mayor de San Simon (CASA 2013).

Parameter	**Method for analysis**
pH	Electrochemical
Turbidity	Nephelometric
Concuctivity	Electrochemical
Color	Hach DR/2000
BOD	Dilution - Winkler
COD	Dichromate oxidation
Coliforms, termo tolerantes	9222-D
Total solids	Gravimetric 180°C
Suspended solids	Calculations
Sulfides	Titration
Flow rates	Floatation method, described in appendix 1

6. Results

The results from interviews and sampling sessions, presented as text, figures and tables.

6.1 Description of the cooperative

The studied neighborhood is a cooperative with their own resources and their own economy. The wastewater treatment system is created by the people who live there and is not funded by the government, it is the people themselves who have made the system work. The cooperative would like to have a better system, but the current system cannot be improved because of various reasons. The cooperative are also lacking money to be able to maintain their system. The municipality has shown interest in taking control of the water and wastewater system in the study area but this is opposed by the steering committee of the cooperative, they think that the government refused to help earlier and therefore they are not interested in getting help now, since they already done so much by themselves[10].

6.2 The organization of the cooperative

The cooperative has an administrative committee that administrates all the work and a vigilancia who controls the administrative committee[11]. The administrative committee is in charge of the economy and also responsible for maintaining the relationship with the state, government and other institutions. There are five members in each committee and three positions are titular. The administrative committee is responsible for all type of administration and other types of activities while vigilancia supervise their work, observe it and help whenever they find it necessary. In the first place it is the administrative committee that is responsible for the cooperative[12]. The vigilancia also contains a technical committee whose task is both to evaluate the administrative committee, but also suggest improvements for both the sewage system and the drinking water system. When a member is elected to any of the cooperative's committees, he or she can stay for a year, but after the first election, he can stay for three more years with a maximum of six years in the current position[13].

The cooperative has three employees who are paid for working there; a secretary, an administrator and a technician[14]. The cooperative's secretary has been working there for almost 7 years. She works about 4.5 hours per day and she is responsible for payments and everything related to the members water consumption. The members obtain a bill every month, and then they go to the secretary to pay for their water consumption[15]. Because the secretary is working at the front desk at the cooperatives office, it is mainly she who receives complaints when something is wrong with the drinking water. Complaints of the sewer system also exist but are not that common[16]. The job she performs is not difficult; the difficulty is to deal with people and their complaints[17]. The secretary also sends out notes to the residents about meetings and other relevant information[18].

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[10] Meeting at the cooperative, 2nd of July 2013
[11] Person number 3, interview 2
[12] Person number 1, interview
[13] Person number 4, interview
[14] Person number 2, interview 1
[15] Person number 2, interview 2
[16] Person number 1, interview
[17] Person number 2, interview 4
[18] Person number 4, interview

The administrator's primary tasks include typical administrative work like work with taxes, governmental institution and health insurance. Also the administrator thinks that the difficult part of his work is when he has to explain for the residents that he not have the ability to solve any of the problems with the drinking water quality, wastewater treatment or the contamination of the river[19].

The work of the secretary, administrator and technician are coordinated with each other. The secretary receives complaints and money from the residents. These complaints she then forward to the administrator and the two of them will have a dialogue about the situation. The administrator gives instructions and also contacts the technician that hopefully fixes the problem. Together they try to do everything they can to solve the problem. Even if the administrator is primarily in contact with the committee is the president of the committee very interested with interacting with all of the employees and has a direct communication with all of them. The committee members who mainly come by to talk to the secretary are the president, the cashier and the secretary. All these three are always interested in being updated about the situation. The employees of the cooperative have no power, but they have the ability to make decisions. If something needs to be purchased and costs more than 50 bolivianos, the employees must consult the committee before purchase is done[20].

All the members of the cooperative pay a connection fee for obtaining water and sewer service and after the payment they received a certificate that has an economic value. The cooperative is very close to deficits in their budget every month, the income every month is about the same as the expenses. Almost all of the money every month goes to paying the salaries of the cooperative's employees, taxes and maintenance costs. If there is any unexpected expense, the cooperative may not be able to pay for it. Those who live in the area think that the water prices are already high and do not want to pay more. The pricing is such that members pay in relation to how much water they consume[21].

6.2.1 Challenges in the organisation

The technical committee has suggested that the drinking water must be treated and that a sedimentation step and removal of iron should be added. These proposals are submitted in reports to the administrative committee, and a challenge is to actually implement these proposals, which sometimes may be difficult. These reports are written twice a year. The residents of the area have access to the reports but the information sent out to the households is short summaries. A private company writes an audit report annually and it is an administrative and unproblematic job. The problems lies in when you want to improve or change something in the cooperative since that means that money will be spent and that is often opposed by the directors of the cooperative[22] [23]. Those who work in the administrative committee feel that it is problematic to have to respond to all the users' complaints since they are complaining a lot[24]. There are also

[19] Person number 4, interview
[20] Ibid.
[21] Person number 2, interview 2
[22] Person number 3, interview 2
[23] Person number 3, interview 3
[24] Person number 1, interview

problems between the two committees since they not always can agree with each other[25].

The organization of the cooperative is very problematic since people are having different opinions in many questions which make it hard to agree with each other. In interviews, it has been told that some of the members of the cooperative feel that some of the members consider themselves to be the owners of the cooperative and thus possess a greater power and therefore does not want to listen to advice from other members. As soon as something new should be implemented in the cooperative there are always discussions and thus a change is difficult to implement since many of the members of the cooperative are unwilling to compromise. This has led to that some persons who have important knowledge do not bother to organize themselves into cooperative since the workload and time consumption is very large[26]. It is always a lot of discussion, which many times is based on that many people believe very strong in their own opinion and don't want to compromise. Everyone wants to have their opinion accepted as the best one[27].

6.2.2 The OTB-organization

In the neighborhood there is also an OTB organization. In some neighborhoods there are water committees in the OTB which then has the tasks with the water system that the cooperative in this area are handling. The main practical differences between having a water committee within the OTB compared to having a water cooperative is that a cooperative be included in all taxes. A cooperative is a legal person and can be assimilated to a small private company and has to pay all kinds of fees as a small private company pays[28].

Sometimes there are discussions within the cooperative to become a water committee instead, mainly due to the desire to get away from the taxes that a cooperative must pay. However, the transition to a water committee will be problematic since the certificate from the cooperative, that all the members have, has an economic value and can no longer be sold if the cooperative not exists anymore, making the situation complicated[29].

Some people involved in both the cooperative and the OTB find it easier to work in OTB. This is because it is a different type of people who are involved in the OTB and there is not the same interest to take care of and protect something that many of the members of the cooperative believe that they need to do[30].

6.2.3 Opinions about the septic tank and the sewage system

The secretary is not receiving many complaints regarding the sewage system and she thinks that the system is working well at the household level. Sometimes it occurs clogging in single households, which the technician can usually solve manually. If the technician cannot solve it, an external company, for example ServiMaster, will come and help. The only major problem with the sewage system is that it has occurred flooding in

[25] Person number 4, interview
[26] Person number 3, interview 2
[27] Person number 3, interview 1
[28] Person number 2, interview 2
[29] Ibid.
[30] Person number 3, interview 1

one of the chambers near the park during the rainy season. Since the majority of the people have their outflow to the sewer system, it happens that this collapses at much rain, however, it very often. The secretary feels that the neighbours do not worry so much about that the wastewater is discharged directly into the river and think it is because they might not feel so concerned. If there was anything that directly irritated them, like smell, she believes that there would be more complaints. The complaints she receives relate mainly to the drinking water[31].

In the user interviews, some of the interviewees have told that they are concerned about the contamination of the river and that this water is used for irrigation of crops[32]. The users think that the government and authorities are responsible for the restoration of the river[33]. Coordination between the people and the authorities is needed to be able to make a change[34]. The users whish for a wastewater treatment system that is better so the river is not contaminated[35]. When the area began populated, those who lived there wash themselves in the river and had picnic at the water which is no longer possible, because of the degree of pollution, which they find very sad[36].

Some of the users who live close to the septic tanks experiencing intense odour which they think is because the tanks not are maintained. These users complain regularly to the cooperative but still no action is taken[37]. Technically, some users would be willing to pay more for a better system but it's not possible for everyone due to economical limits[38]. There are also users who feel that the system is efficient and does not wish either that it is replaced or changed in any way[39].

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[31] Person number 2, interview 4
[32] Interview 2, San Sedro 1/8
[33] Ibid.
[34] Person number 5, interview
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Ibid
[39] Person number 6, interview

6.3 Sample results from the neighborhood

The following section will show the results from the sampling sessions in the neighborhood.

6.3.1 Results from flow 1 plan A

Table 5 shows the results from sampling point 1 (flow 1) in the neighborhood. Samples were taken the 15^{th} and 31^{st} of July 2013.

Table 5. Results from point 1

	Sampling 1 (15/7-13)	**Sampling 2 (31/7-13)**
Coliforms (UFC/100 mL)	$9.7 \cdot 10^7$	$1.4 \cdot 10^7$
Total solids (mg/L)	825	1328
Dissolved solids (mg/L)	750	1278
Suspended solids (mg/L)	75	50
Sulphides (mgS/L)	4.49	7.02
BOD/DBO$_5$ (mgO$_2$/L)	263	188
COD/DQO (mgO$_2$/L)	638	428
pH	8.16	7.88
Conductivity (µS/cm)	1450	1752

6.3.2 Results from flow 2 plan A

Table 6 shows the results from sampling point 2 (flow 2) in the neighborhood. Samples were taken the 15^{th} and 31^{st} of July 2013.

Table 6. Results from point 2

	Sampling 1 (15/7-13)	**Sampling 2 (31/7-13)**
Coliforms (UFC/100 mL)	$1.3 \cdot 10^7$	$3.9 \cdot 10^7$
Total solids (mg/L)	1473	1380
Dissolved solids (mg/L)	710	1332
Suspended solids (mg/L)	763	42
Sulphides (mgS/L)	5.01	6.16
BOD/DBO$_5$ (mgO$_2$/L)	258	490
COD/DQO (mgO$_2$/L)	806	1261
pH	8.20	7.33
Conductivity (µS/cm)	1410	998

6.4.3 Results from outflow A

Table 7 shows the results from outflow A in the neighborhood. Samples were taken the 15th and 31st of July 2013.

Table 7. Results from outflow A

	Sampling 1 (15/7-13)	Sampling 2 (31/7-13)
Coliforms (UFC/100 mL)	$2.0 \cdot 10^7$	$7.1 \cdot 10^7$
Total solids (mg/L)	820	1068
Dissolved solids (mg/L)	610	1036
Suspended solids (mg/L)	210	33
Sulphides (mgS/L)	5.80	7.47
BOD/DBO$_5$ (mgO$_2$/L)	232	338
COD/DQO (mgO$_2$/L)	628	684
pH	7.80	8.06
Conductivity (µS/cm)	1150	1616
Flow (m^3 s^{-1}) (mean value)	0.000679	0.000465

6.3.4 Results from outflow B

Table 8 shows the results from outflow B in the neighborhood. Samples were taken the 15th and 31st of July 2013.

Table 8. Results from outflow B

	Sampling 1 (15/7-13)	Sampling 2 (31/7-13)
Coliforms (UFC/100 mL)	$4.6 \cdot 10^7$	$1.7 \cdot 10^7$
Total solids (mg/L)	963	820
Dissolved solids (mg/L)	450	780
Suspended solids (mg/L)	513	40
Sulphides (mgS/L)	4.82	5.25
BOD/DBO$_5$ (mgO$_2$/L)	150	310
COD/DQO (mgO$_2$/L)	426	618
pH	7.66	8.40
Conductivity (µS/cm)	890	1627
Flow (m^3 s^{-1}) (mean value)	0.00143	0.001285

6.3.5 Mean values

Table 9 shows the mean values for outflow A and outflow B. Values written in red indicates that the value is above the maximum allowable limit for liquid discharges in Bolivia.

Table 9. Mean values for outflow A and outflow B

	Limit value	Outflow A	Outflow B
Coliforms (UFC/100 mL)	1000	$4.5 \cdot 10^7$	$3.1 \cdot 10^7$
Total solids (mg/L)	-	944	891
Dissolved solids (mg/L)	-	823	615
Suspended solids (mg/L)	60	121	276
Sulphides (mgS/L)	2	6.63	5.03
BOD/DBO$_5$ (mgO$_2$/L)	80	285	230
COD/DQO (mgO$_2$/L)	250	656	522
pH	6-9	7.93	8.03
Conductivity (µS/cm)	-	1383	1258
Flow (m^3 s^{-1})	-	0.000572	0.001357

6.3.6 Results from the flow measurement

Figure 9 shows the flow at outflow A, measured at both 15th and 31st of July.

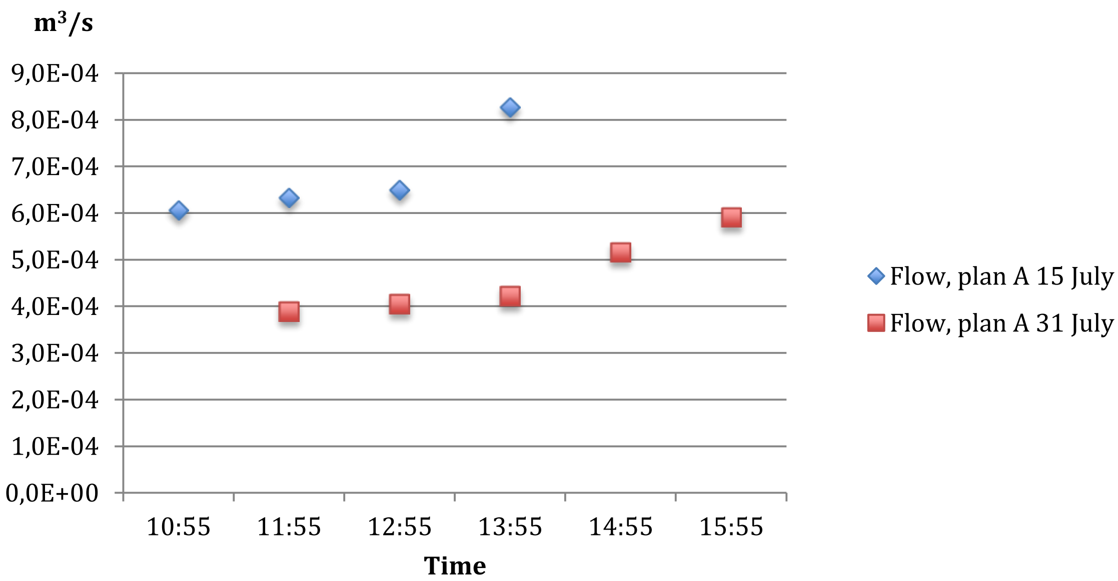

Figure 9. Results from the flow measurements.

Figure 10 shows the flow at outflow B, messured at both 15th and 31st of July.

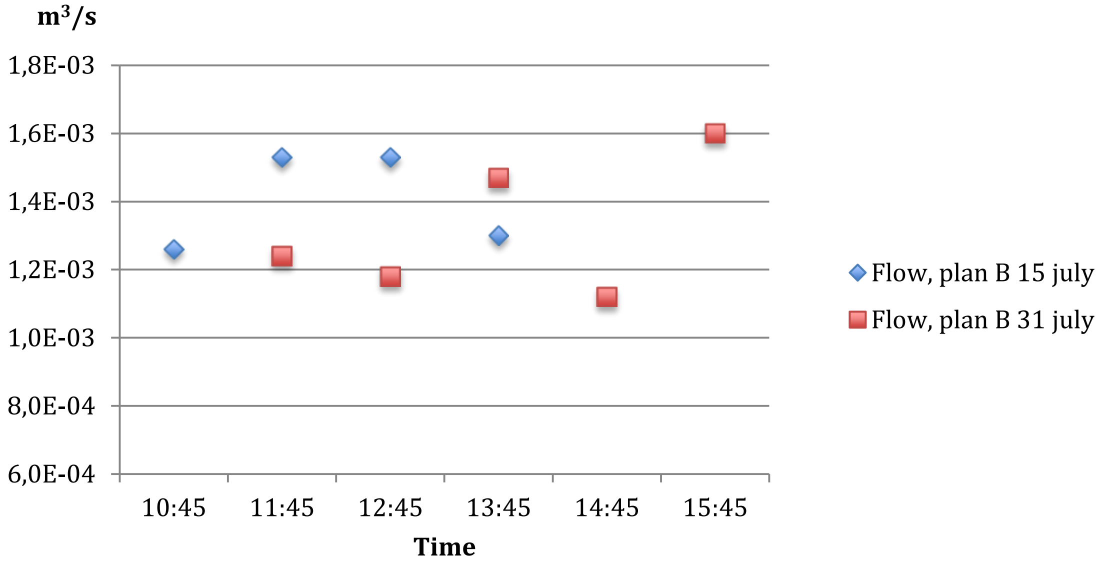

Figure 10. Results from the flow measurements.

6.3.7 Coliform- and BOD concentrations

Figure 11 shows the change in coliform concentration before and after maintenance with ServiMaster.

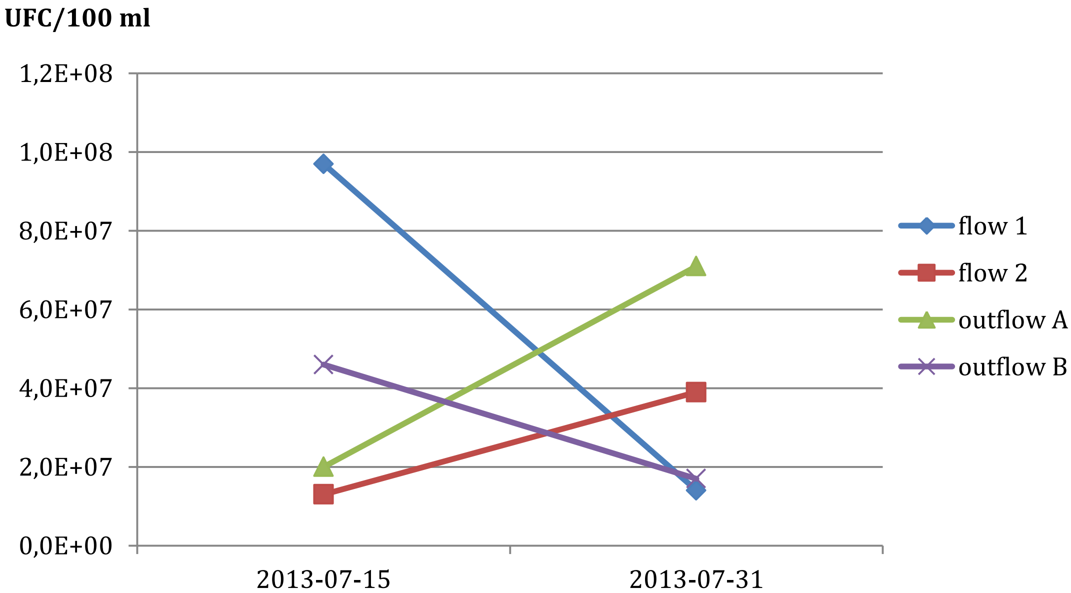

Figure 11. Change in coliform concentrations.

Figure 12 shows the change in BOD concentration before and after maintenance with ServiMaster.

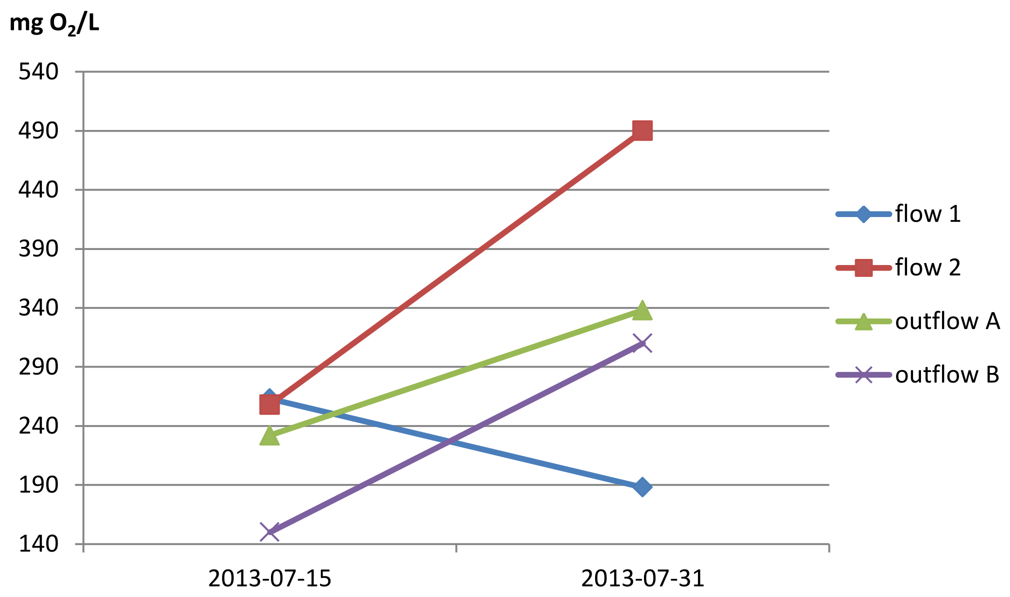

Fig 12. Change in BOD concentration.

For more plotted comparison, see Appendix 5.

6.5 Sample results from the Rio Rocha

The following section will show the results from the sampling sessions from Rio Rocha

6.5.1 Puente de Servicio de Caminos (point 1)

Table 10 shows the results from Servicio de Caminos in the Rio Rocha. Samples were taken the 9th and 23th of July 2013 and 7th of August 2013.

Table 10. Results from Puente de Servicio de Caminos

	Sampling 1 (9/7-13)	**Sampling 2 (23/7-13)**	**Sampling 3 (7/8-13)**
Coliforms (UFC/100 mL)	$1.0 \cdot 10^7$	$7.5 \cdot 10^6$	$1.2 \cdot 10^6$
Turbidity (NTU)	160.00	100	-
Color (PtCo units)	1960	3480	-
BOD/DBO$_5$ (mgO$_2$/L)	51	141	105
COD/DQO (mgO$_2$/L)	476	388	564
pH	8.02	7.69	7.52
Conductivity (µS/cm)	437.00	1335	1483
Flow (m^3 s^{-1})	0.204	0.189	0.198

6.5.2 Puente Huayllni (point 2)

Table 11 shows the results from Huayllni in the Rio Rocha. Samples were taken the 9th and 23th of July 2013 and 7th of August 2013.

Table 11. Results from Puente Huayllni

	Sampling 1 (9/7-13)	**Sampling 2 (23/7-13)**	**Sampling 3 (7/8-13)**
Coliforms (UFC/100 mL)	900	$1.4 \cdot 10^3$	$1.5 \cdot 10^3$
Turbidity (NTU)	1.90	1.60	-
Color (PtCo units)	24	48	-
BOD/DBO$_5$ (mgO$_2$/L)	27	14	15
COD/DQO (mgO$_2$/L)	38	42	24
pH	8.06	7.93	8.48
Conductivity (µS/cm)	554.00	575	522
Flow (m^3 s^{-1})	0.0315	0.0272	0.0396

6.5.3 Mean values

Table 12 shows the mean values for Puente de Servicio de Caminos and Puente Huayllni. Values written in red indicates that the value is above the maximum allowable limit for liquid discharges in Bolivia.

Table 12. Mean values for point 1 and point 2

	Limit value	**Point 1**	**Point 2**
Coliforms (UFC/100 mL)	1000	$6.2 \cdot 10^6$	$1.3 \cdot 10^3$
Turbidity (NTU)	-	210.00	1.75
Color (PtCo units)	-	2720	36
BOD/DBO$_5$ (mgO$_2$/L)	80	99	19
COD/DQO (mgO$_2$/L)	250	476	35
pH	6-9	7.74	8.16
Conductivity (µS/cm)	-	1085	550
Flow (m^3 s^{-1})	-	0.197	0.0328

6.5.4 Flow

Figure 13 shows how the flow at Puente de Servicio de Caminos (Point 1) and Puente Huayllni (Point 2) has varried from March to August.

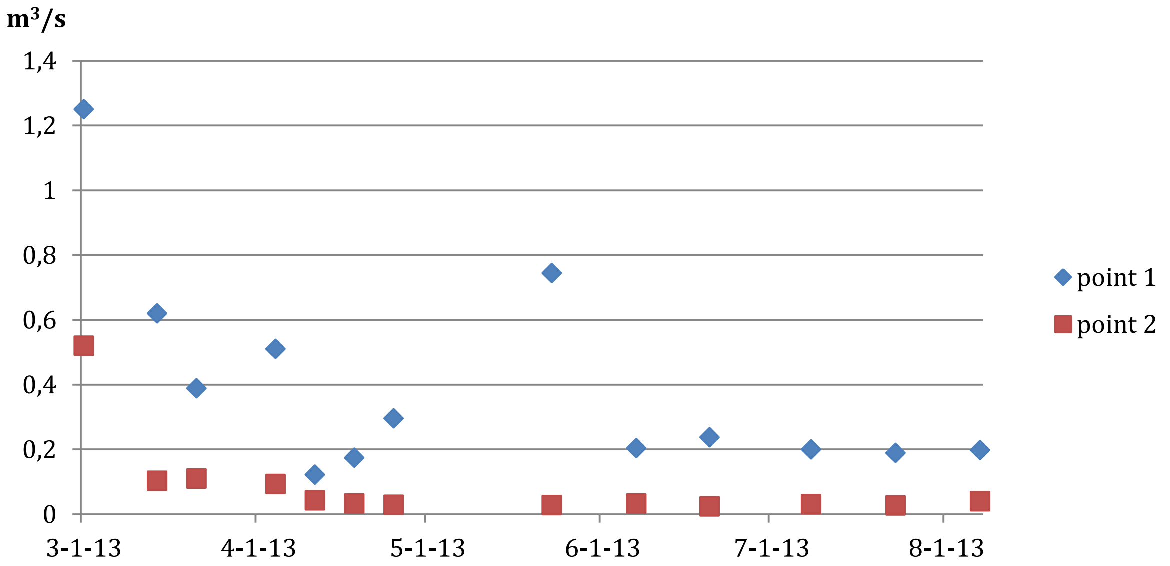

Figure 13. Flow data obtained from Puente de Servicio de Caminos and Puente Huayllni.

6.5.5 BOD

Figure 14 shows how the BOD concentration at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

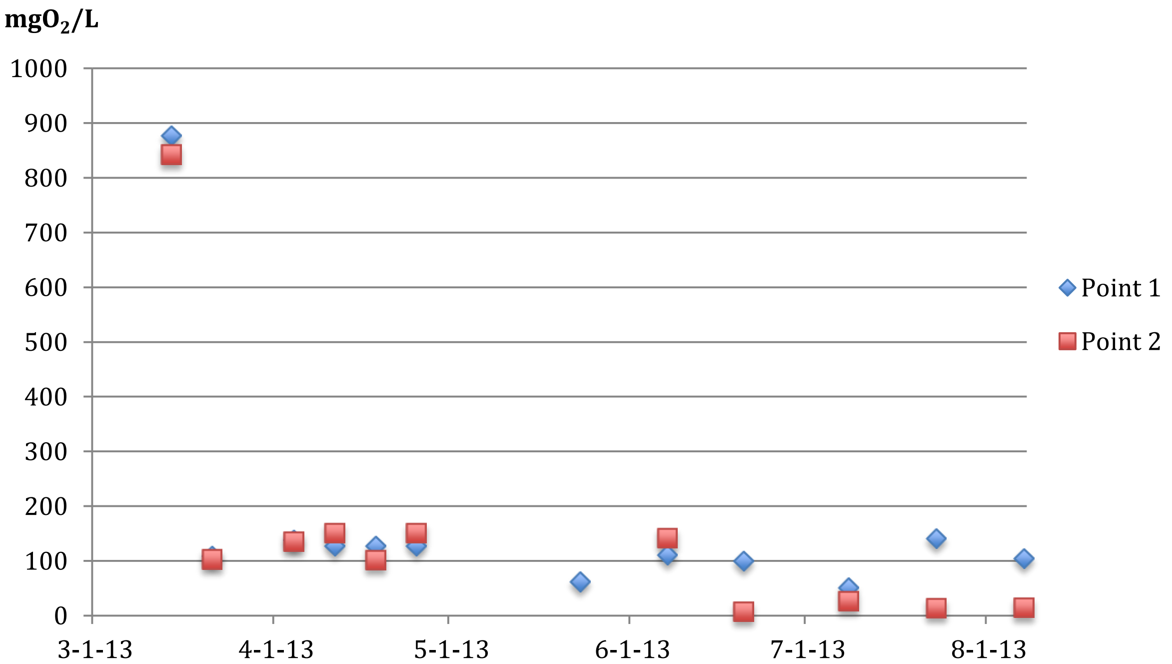

Figure 14. BOD-concentrations at Puente de Servicio de Caminos and Puente Huayllni.

6.5.6 COD

Figure 15 shows how the COD concentration at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

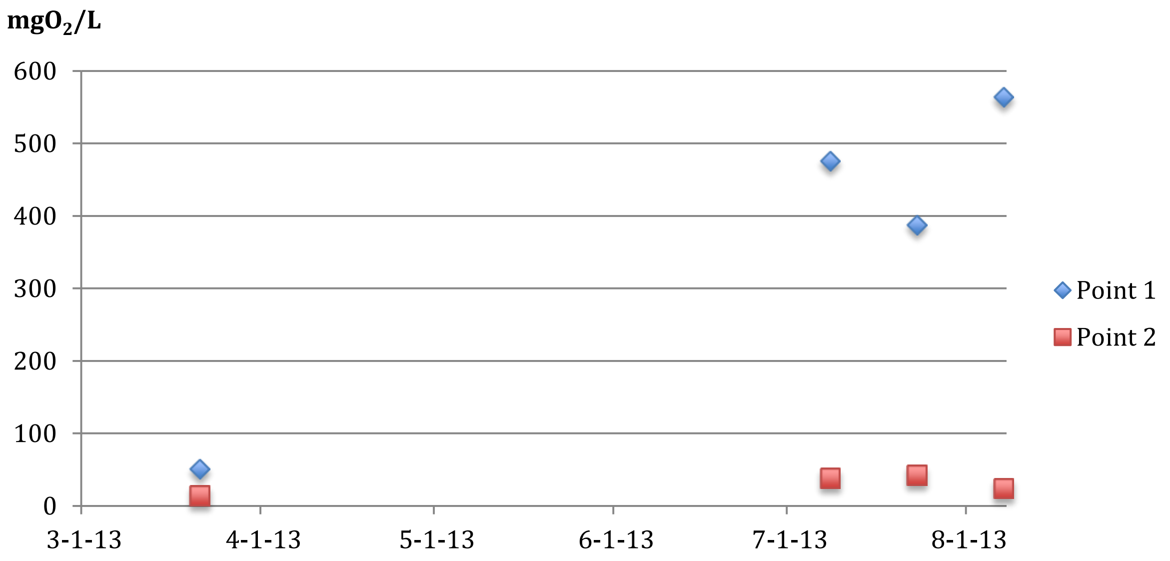

Figure 15. COD-concentrations at Puente de Servicio de Caminos and Puente Huayllni.

6.5.7 Coliforms

Figure 16 shows how the concentration of coliforms at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

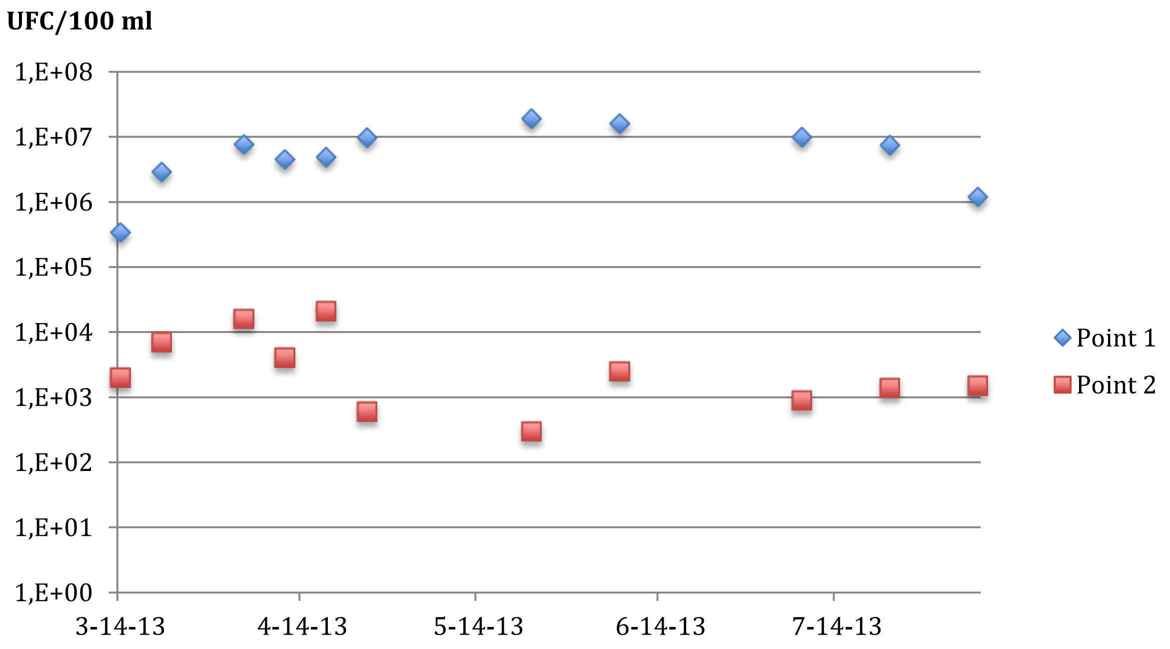

Figure 16. Concentration of coliforms at Puente de Servicio de Caminos and and Puente Huayllni.

6.5.8 Turbidity

Figure 17 shows how the turbidity at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

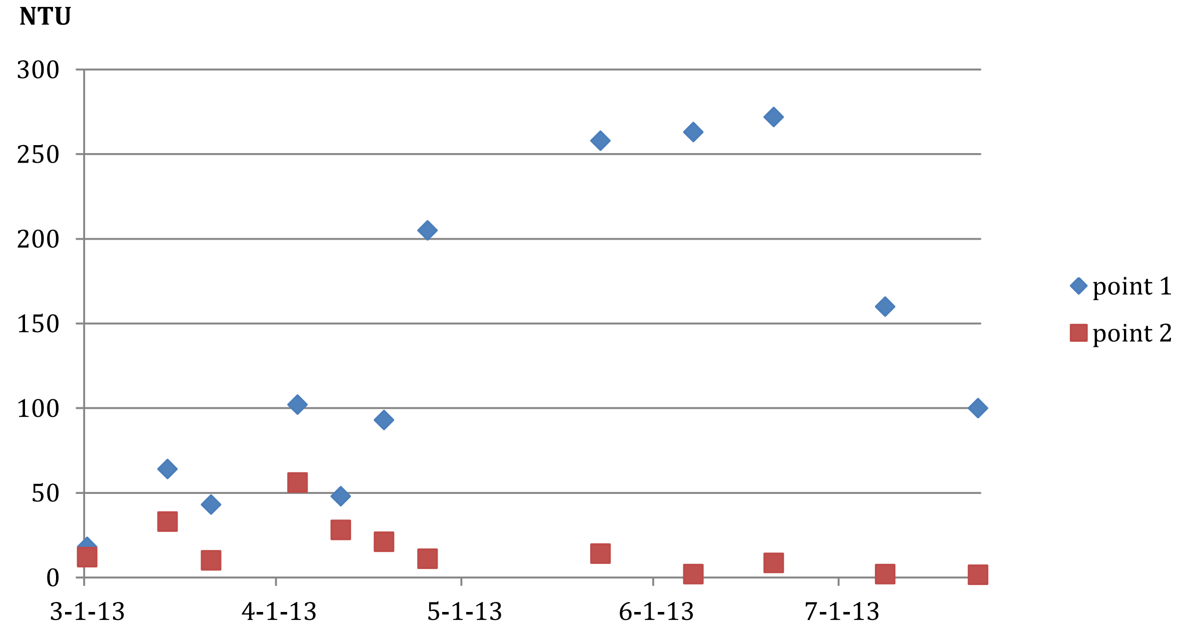

Figure 17. The turbidity at Puente de Servicio de Caminos and and Puente Huayllni between March and August.

6.5.9 Color

Figure 18 shows how the parameter color at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

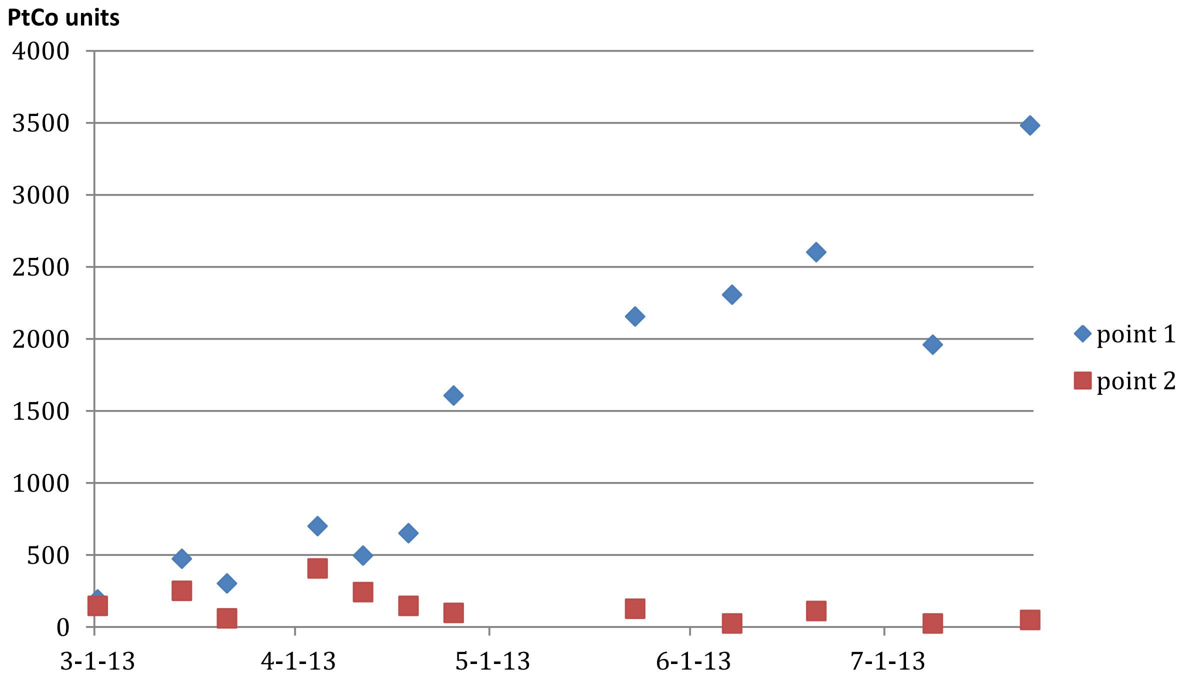

Figure 18. The parameter color at Puente de Servicio de Caminos and and Puente Huayllni.

6.5.10 pH

Figure 19 shows how the pH value at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

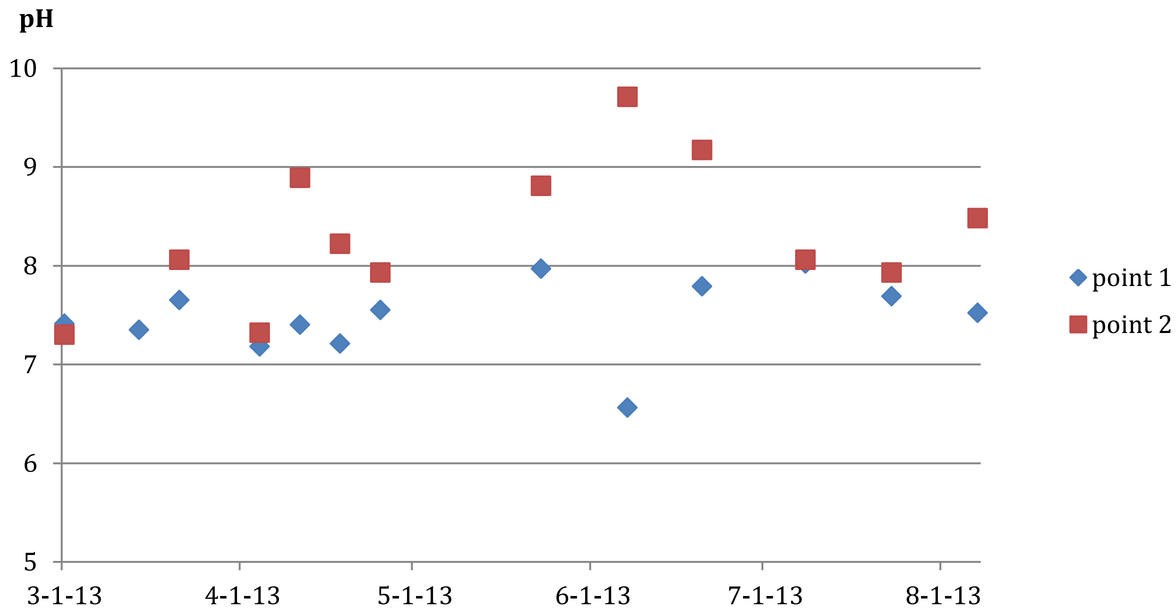

Figure 19. The pH value at Puente de Servicio de Caminos and and Puente Huayllni.

6.5.11 Conductivity

Figure 20 shows how the conductivity at Puente de Servicio de Caminos and Puente Huayllni has varried from March to August.

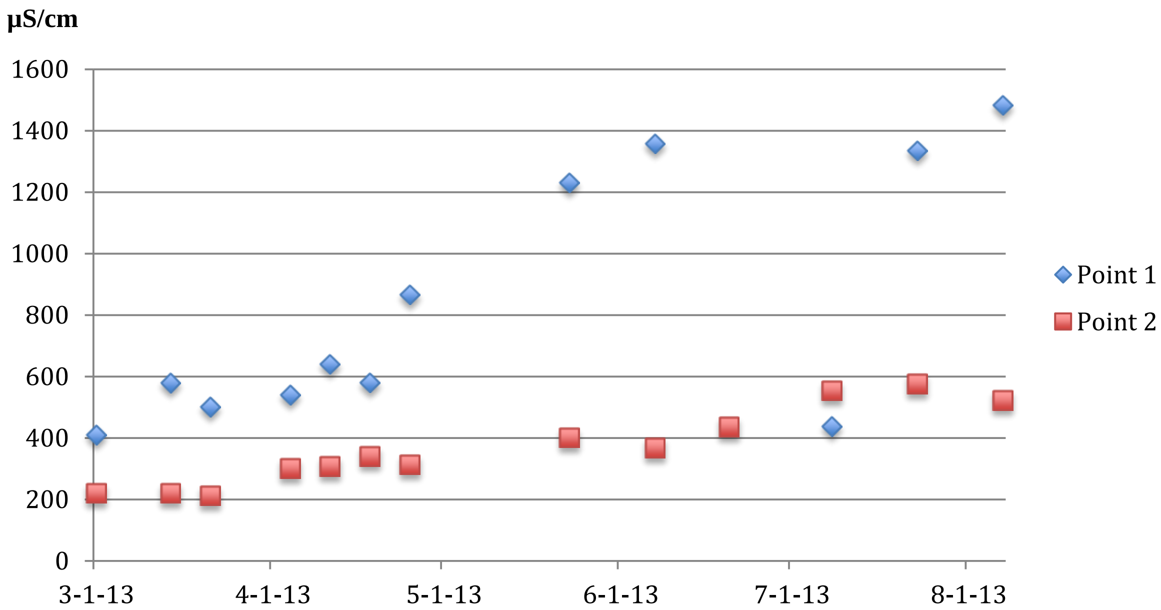

Figure 20. The conductivity value at Puente de Servicio de Caminos and and Puente Huayllni.

7. Analysis

The following chapter describes the MCA-analysis that was made with the material collected from the interviews presented in the result section. The analysis were performed according to the description by Gamper, 2006.

7.1 Analysis of interviews

To set the criteria's for the MCA-analysis the material collected from interviews, meetings and observations were put together into different categories. The following criteria's were then chosen for the analysis;

7.1.1 Construction cost (A)

Since both key persons of the cooperative and the many of the members told in interviews that the cooperative has a poor economy, it is important that the construction cost for the waste water treatment plant will not be too high. However, this does not mean that a more expensive solution not is an option, but in that case the solution should have the potential to be funded externally in some way. In the grading in the MCA-matrix a low point indicates that the construction cost will be expensive for the cooperative while a high point corresponds to a low construction cost or that it's possible for the cooperative to receive external funds.

7.1.2 Construction; time and material (B)

Since the members of the cooperative find it difficult to agree and make decisions, it is important that the wastewater treatment plant is easy construct and to get in place. It is also important to not include materials that are difficult to find or that the work with the construction is difficult to perform. The reason why this is of importance is that it is important to avoid situations where the members cannot agree with each other, since that kind of situation will delay, or in worst place cancel, the construction of the treatment plant. In the MCA-matrix, a low point is equivalent to that the design is time-consuming, complex and requires material that can be hard to find, while a high point corresponds to a simple design.

7.1.3 Maintenances; cost and performance (C)

From both interviews and observations it has been revealed that the cooperative has difficulties with organizing themselves when it comes to the issue with the waste water treatment plant. Therefore, it is of interest that the chosen solution does not require expensive maintenance, and as little maintenance as possible. If maintenance is required, it is desirable that this can be done by the cooperative's own technician without external help or financial resources required. In the MCA-matrix a low point corresponds to that maintenance is difficult and expensive, while a high point corresponds to no maintenance at all.

7.1.4 Landscape impact (D)

In interviews, a desire to preserve the green area located between neighborhood and the river has been expressed. The neighbors in the area want to be able to have this area as a park and sports court, and therefore it is not desirable to include this area as a part of the wastewater treatment plant. If the area were included in the new wastewater treatment plant it is likely that that would cause conflicts in the cooperative and complicate the implementation process. In the MCA-matrix, a low point corresponds to a large landscape impact, while a high point corresponds to that the treatment plant does not take much space and does not affect the green area.

7.1.5 Environmental impact (E)

The background for this criterion is the sampling results from both the neighborhood and the River Rocha and the observations that were made during the sampling sessions. It is of large importance that the contamination of the river decreases as much as possible since the environmental impacts from the contaminated river is a big concern for the moment. In the MCA-matrix, a low point corresponds to a large environmental impact on the river, ground water and drinking water, while a high point corresponds to a safe system with no environmental impact at all.

7.2 MCA-analysis

All the suggested waste water treatment solutions are graded for each criterion (A-E). The maximum grade that a criterion can have is 5 points and the maximum total is 25 points.

Table 12. MCA-analysis

	A	B	C	D	E	Summary (max 25 p)
Keep the current system	5	5	1	2	1	**14**
Septic tank + leach field	3	3	2.5	3.5	3	**15**
Septic tank + constructed wetland	3	3.5	2.5	3	3.5	**15.5**
ABR + leach field	3	3	2.5	3.5	3	**15**
ABR + constructed wetland	3	3.5	2.5	3	3.5	**15.5**
Anaerobic filter + leach field	3	2.5	2.5	3.5	3.5	**15**
Anaerobic filter + constructed wetland	3	3	2.5	3	4	**15.5**
Anaerobic biogas reactor + leach field	3.5	2	3.5	3.5	3	**15.5**
Anaerobic biogas reactor + constructed wetland(Aguatuya technique)	3.5	2.5	3.5	3	3.5	**16**

8. Discussion of the results

To evaluate the efficiency of the septic tank in the studied area, water samples were taken before and after the tank to see how well the water is treated by the septic tank. Since it was not possible to empty the tank from sediment due to the misconstruction, it was not possible to maintain the tank with ServiMaster as planned. This means that there is no measurement of reliable character available to describe how effective the tank is when it is maintained, since maintains not was possible in this study. The conclusions that can be drawn from the outflows in the neighborhood is that both outflow A and outflow B discharges far too high concentrations of both coliforms, suspended solids, sulphides, BOD and COD. The hypothesis was that the outflow A would be somewhat cleaner than the outflow B because septic tank A is still working. This turned out to not be true, since the concentrations of the above parameters are quite similar for both outflow A and outflow B. The conclusion to be drawn from this is that the septic tank is not effective and that wastewater treatment basically consists of sewage discharged directly into the river.

The results from the interviews indicates much of what was suspected when this master thesis started; the problem in the cooperative lies not in that the knowledge does not exist, but rather in challenges with the organisation of the cooperative around the wastewater issue. It is likely that this problem occurs in similar neighborhoods in Cochabamba, meaning that this area can be considered as a good example of how a small residential organize themselves around water issues and the conflicts that may arise. Therefore, it's likely that the case study in this neighborhood can be applied to similar neighborhoods in the area. This fact also answers the question why the tank is not maintained in a better way, since it seems to be caused by organizational challenge's rather than lack of knowledge in the field. In many of the interviews the interviewees told that that lack of money would be one of the reasons why the wastewater system is not maintained better.

The interviews has also been the basis for answering the question what improvements could be made and what would happen if these were implemented. In the MCA-matrix have solutions with a simple structure, easy and inexpensive maintenance, small landscape impact and low environmental impact been promoted. The only solution from the theory chapter that not is a part of the analysis is the soak pit, since this solution only is a good option for rural areas. A soak pit will also maybe not be a safe option for the studied area because the risk for contamination of both springs and ground water. All of these criteria in the analysis, except the last one, have been based on the interviews. The criteria low environmental impact has been developed based on observation and is not information that has been collected through the interviews mainly. The interviewees only talked about the river and their concern about the contamination when direct questions about this were asked. For example, in many of the interviews the interviewees were asked to describe their opinions about the Rio Rocha and if they were concerned about the environmental issue or not. Thus, this criterion is not a desire by the neighbours, but is rather a consequence of the results from the water sampling and own observations. This means that if the analysis would exclusively focus on what the people who live in this neighborhood wants, this criterion should be excluded.

Based on the MCA-analysis, an anaerobic biogas reactor as primary treatment and a constructed wetland as secondary treatment have been determined to be the best solution for the cooperative. This theoretical proposal is almost only based what the interviewees expressed during the interviews. Since it was not possible to interview all the neighbours this can be a source of error, since other opinions may have been expressed if other neighbours had been interviewed. One important conclusion from the MCA-analysis is the matrix itself and the analytical tools that have been developed. Based on the criteria and scoring system, it is possible that in the same matrix include other types of solutions. It is also possible to add so-called weighting points to enable a criterion to have a greater influence on the outcome than another. Weighting points could easily be implemented by the cooperative itself, and then would perhaps a different result be obtained. Since it was impossible to include all possible wastewater treatment technologies in the matrix it also possible that the results would have been different if other techniques was chosen. The solution with the winning score is the one that is used by the organization Aguatuya which is already in operation in other neighborhoods in Cochabamba. It has for sure its advantages to choose a design that is already established in the area with satisfying treatment results, and therefore the cooperative should consider this solution rather than redo the MCA-analysis and put other treatment options in it. Since all the solutions in the MCA-analysis has a very similar score a possible way to find the best solution is to only look at the criteria that is of largest importance. For example, if cheap maintenance is of most importance one of the techniques with anaerobic biogas reactor should be chosen since these techniques are having the highest score for maintenance (criterion C).

The samples from the Rio Rocha shows a reduced flow in the winter, when the dry season starts. As observed, the flow is stronger at point 1 than point 2. The flow at point 1 has a peak in early dry season when the flow theoretically should decrease. This is due to that in the area there are also other water sources than the actual river and rain water, such as wastewater, which at the specific time of measurement contributed to a greater flow (Aguilar 2013). The concentration of coliforms is consistently high, exceeding allowable limits. Point 1 has a consistently higher concentration than point 2, which is due to that point 1 is downstream (closer to Cochabamba), where the river is more polluted because of sewage, garbage and car washes. The growth of coliforms at point 1 in the early dry season is due to the lack of rainfall and therefore the concentration of wastewater in the river becomes higher. The diverse behaviour in coliform concentration at point 2 may be due to that this measuring point is exposed to more temporary increases of coliforms related to the release of shells, dead plants and animals and therefore the measurement data shifts for each sampling session. An increased amount of sunlight could have a killing effect on the coliforms, but this is unlikely affect this study significantly (Aguilar2013). The increase in turbidity at point 1 could be explained by human activity in the area while the decay at point 2 is due to the lack of human activities that make the water cloudy. The pH is higher at point 2 than at point 1 because emission of organic material at point 1 is higher which reduces the water acidity (Aguilar 2013).

Overall, it is possible to conclude that point 1 in much more affected by pollution and other human activities than point 2 , which is due to that point 1 is downstream (located closer to the centre of Cochabamba). This also answers the question how the Rio Rocha is influenced by neighborhood in the area. If more neighborhoods along the river bank did implement proper wastewater treatment system, the pollution at point 1 would thus decrease. Sampling results show significantly higher levels of measured substances at point 1 than at point 2. The average value during the dry season (last 3 measurements) exceeds the recommended values for BOD, COD and coliforms at point 1, while only the value for coliforms is exceeded at point 2. Had there been no impact from human activities should not the measurement data from point 1 and point 2 differ that much from each other.

8.1 The methodology

A weakness in this study is that at the start of the project it was meant to empty the septic tank properly and that there would then be differences in the measurement of outflow A when the septic tank has been emptied compared to when it was not. Further, it was then also thought that the proposed improvements would be able to focus on the existing septic tank with respect to how this could be improved and also to spread information in the cooperative on how maintenance should be done, how they can take care of their tank in the best way, how many households that is possible to connect and thing like that. When it was discovered that the tank was not possible to empty the study was also forced to change focus when the proposed improvements only could be theoretical then, since the septic tank could be considered as not working and impossible to improve. With this experience it would have been better to perhaps in the beginning of the study to think broader and not narrow the study too early. If the tank had been possible to empty it would also have been good to do sampling both before and after emptying at more than one time, since samples taken at only one times may not give significant results. However, this was also a cost issue because it cost money to get the samples analysed.

At all interviews a translator was used, which also may have had some influence over the results since it was only possible to get summaries of the things that were said translated, and not word by word. In addition, the interviews was somewhat disjointed since they were constantly interrupted to do translation. Interviews without a translator would probably have produced better and more open discussions which had been able to add data to the result.

8.2 Further research

Further studies in this area could be to develop the MCA-analysis with respect to both the wastewater solutions included as well as the grading. A study to follow this one could also be the actual introduction of a new treatment plant in the area, where all parts, both financial and construction, are taken into account.

8.3 Conclusions

The aim of this master thesis was to study, evaluate and improve the wastewater treatment in a neighborhood in the municipality of Sacaba. The conclusion is that the system has been studied and described very well through interviews and observations. Theoretical improvements have been made and a useful tool has been developed which can be the basis for further work in the area. The most useful information that this thesis can contribute to research is the knowledge of the specific situation in this neighborhood and that this knowledge could also be applied to similar neighborhoods in Cochabamba. This can for example be knowledge about the organization within the cooperative and the challenges they are facing when it comes to finding a suitable solution for their waste water treatment system. The improvement proposal from the

MCA-analysis should be considered by the cooperative since it's very likely that this is the best solution for the neighborhood. It's highly recommended that the cooperative chose this solution since it's already in operation in the area of Cochabamba.

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Appendix 1

Calculations of the flow rates in the river Rocha. In all measurements and calculations a length of 4 meters of the river were used, which was measured at the beginning of the sampling session. The flow measurements were made by determining how many seconds it takes for a small piece of wood to float these 4 meters from A to B and then determine the volume of water by also measuring the river's depth and width.

Sampling 1 – 9th of July, 2013

Puente de servicio de caminos (point 1)

For section A, the following width and depths were measured:

Width (m)	1.95	1.5	1	0.5	0
Depth (m)	0.25	0.21	0.18	0.12	0.01

For section B, the following width and depths were measured:

Width (m)	3.2	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.05	0.11	0.18	0.14	0.09	0.07	0.08	0.095

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	(1)	6.57	6.30	6.45

- ➔ Mean value = 6.44 s (The value 1 s were not included)

To obtain the area of A and B were the sections divided into smaller pieces consisting of rectangles and triangles. The area of these small pieces were then calculated separately and summarized.

Example of calculation

$$Area\ 1 = (0.45\ m\ \cdot 0.21\ m) + \frac{(0.25\ m - 0.21\ m) \cdot 0.45\ m}{2}$$

$$\rightarrow Area\ 1 = 0.0945\ m^2 + 0.009\ m^2 = 0.1035\ m^2$$

The same calculations were done for all the small sections and the following areas were obtained; area 2 = 0.0975 m^2, area 3 = 0.075 m^2 and area 4 = 0.0325 m^2 → Total area A = 0.3085 m^2

For section B, the total area was calculated to: A = 0.016 + 0.0725 + 0.08 + 0.0575 + 0.04 + 0.0375 + 0.04375 = 0.34725 m^2

The volume of the total section will then be:

$$V = \frac{A + B}{2} \cdot 4\ m = \frac{0.3085\ m^2 + 0.34725\ m^2}{2} \cdot 4\ m = 1.3115\ m^3$$

Thus, the flow will be:

$$Q = \frac{1.3115\ m^3}{6.44\ s} = 0.2036\ m^3 s^{-1}$$

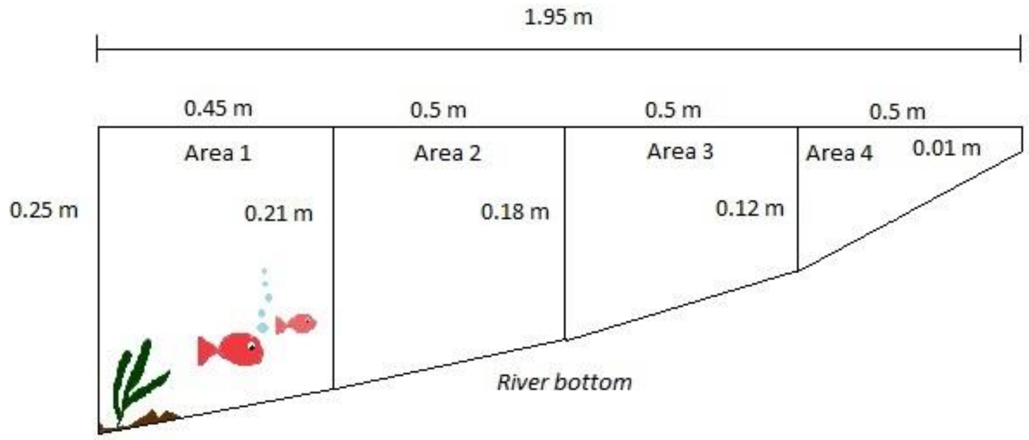


Fig x. Illustration of how the area of section A was calculated (Arnold 2013)**.**

Puente Huayllni (point 2)
For section A, the following width and depths were measured:

Width (m)	3.5	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.08	0.11	0.13	0.11	0.09	0.06	0.03	0

For section B, the following width and depths were measured:

Width (m)	4.4	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.03	0.12	0.14	0.12	0.14	0.13	0.09	0.03

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	44.82	39.52	(58.14)	44.82

- ➔ Mean value = 43.05 s (The value 58.14 s were not included)

Total area for A = 0.0475 + 0.06 + 0.06 + 0.05 + 0.0375 + 0.0225 + 0.0075 = 0.225 m^2

Total area for B = 0.105 + 0.065 + 0.065 + 0.065 + 0.0675 + 0.055 + 0.03 = 0.4525 m^2

Total volume V = 1.355 m^3

The flow Q = 0.03147 $m^3\ s^{-1}$

Sampling 2 – 23th of July, 2013

Puente de servicio de caminos (point 1)
For section A, the following width and depths were measured:

Width (m)	1.9	1.5	1	0.5	0
Depth (m)	0.16	0.19	0.14	0.13	0.03

For section B, the following width and depths were measured:

Width (m)	3.15	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.10	0.12	0.20	0.08	0.13	0.11	0.08	0.03

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	6.70	6.12	6.97	6.07

➔ Mean value = 6.465 s

Total area for A = 0.07 + 0.0825 + 0.0675 + 0.04 = 0.26 m^2

Total area for B = 0.0165 + 0.08 + 0.07 + 0.0525 + 0.06 + 0.0475 + 0.0275 = 0.354 m^2

Total volume V = 1.228 m^3

The flow Q = 0.189 $m^3\ s^{-1}$

Puente Huayllni (point 2)
For section A, the following width and depths were measured:

Width (m)	3.35	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.03	0.11	0.12	0.10	0.10	0.10	0.085	0.025

For section B, the following width and depths were measured:

Width (m)	3.5	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.03	0.09	0.14	0.10	0.13	0.11	0.05	0.01

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	42.92	47.80	(35.59)	(52.45)	48.40

➔ Mean value = 46.37 s (The value 35.59 s and 52.45 s were not included)

Total area for A = 0.0245 + 0.0575 + 0.055 + 0.05 + 0.05 + 0.04625 + 0.0275 = 0.31075 m^s

Total area for B = 0.03 + 0.0575 + 0.06 + 0.0575 + 0.06 + 0.04 + 0.015 = 0.32 m^2

Total volume V = 1.2615 m^3

The flow Q = 0.0272 $m^3 s^{-1}$

Sampling 3 – 7th of August, 2013

Puente de servicio de caminos (point 1)
For section A, the following width and depths were measured:

Width (m)	1.9	1.5	1	0.5	0
Depth (m)	0.18	0.19	0.16	0.13	0.03

For section B, the following width and depths were measured:

Width (m)	3.10	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.12	0.15	0.19	0.15	0.13	0.11	0.07	0.02

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	6.88	6.57	6.66	6.39

➔ Mean value = 6.625 s

Total area for A = 0.074 + 0.0875 + 0.0725 + 0.04 = 0.274 m^2

Total area for B = 0.0135 + 0.085 + 0.085 + 0.07 + 0.06 + 0.045 + 0.0225 = 0.381 m^s

Total volume V = 1.31 m^3

The flow Q = 0.1977 $m^3 s^{-1}$

Puente Huayllni (point 2)
For section A, the following width and depths were measured:

Width (m)	3.9	3.5	3	2.5	2	1.5	1	0.5	0
Depth (m)	0.01	0.14	0.17	0.18	0.16	0.11	0.08	0.06	0.01

For section B, the following width and depths were measured:

Width (m)	3.8	3.5	3	2.5	2	1.5	1	0.5	0
Depth (m)	0	0.05	0.18	0.20	0.19	0.16	0.08	0.08	0.02

The following times were measured for a small piece of wood to float the 4 meters from A to B:

Times (s)	48.33	41.67	(79)	48.51	42.52	51.75	45.1

➔ Mean value = 46.31 s (The value 79 s were not included)

Total area for A = 0.03 + 0.0775 + 0.0875 + 0.085 + 0.0675 + 0.0475 + 0.035 + 0.0175 = 0.4475 m^2

Total area for B = 0.0075 + 0.0575 + 0.095 + 0.0975 + 0.0875 + 0.06 + 0.04 + 0.025 = 0.47 m^3

Total volume V = 1.835 m^3

The flow Q = 0.03962 m^3 s^{-1}

Appendix 2

Calculations of water flow from the plan A and plan B in the neighborhood to the Rio Rocha. Flow rates were determined by measuring how long it takes to fill a bucket with the volume of 10 litres.

Sampling 1 – 15th of July 2013

Flow from plan A

From plan A, the following times were measured:

Hour	10:55	11.55	12.55	13.55
Time	16.15 16.74 16.65	16.20 15.93 15.22	14.35 15.70 16.15	12.19 12.24 12.01
Mean value (s)	16.51	15.78	15.40	12.09
Flow (m^3 s^{-1})	0.000606	0.000633	0.000649	0.000827

➔ Mean value flow = 0.000679 m^3 s^{-1}

Flow from plan B

From plan B, the following times were measured:

Hour	10:45	11:45	12:45	13:45
Time	7.29 8.46 8.01	6.57 6.66 6.43	6.21 6.16 5.98	8.28 7.56 7.29
Mean value (s)	7.92	6.55	6.12	7.71
Flow (m^3 s^{-1})	0.00126	0.00153	0.00163	0.00130

➔ Mean value flow = 0.00143 m^3 s^{-1}

Sampling 2 – 31th of July 2013

Flow from plan A

From plan A, the following times were measured:

Hour	11.55	12.55	13:55	14:55	15:55
Time (s)	25.2 (27.27) 25.69 26.23	25.06 24.48 24.52	23.89 23.71 23.49 23.71	19.80 19.17 19.35 19.12	17.41 16.51 16.82 (18.08)
Mean value (s)	25.71	24.69	23.70	19.36	16.91
Flow (m^3 s^{-1})	0.000389	0.000405	0.000422	0.000516	0.000591

➔ Mean value flow = 0.000465 m^3 s^{-1} (values in parentheses were not included in the calculations)

Flow from plan B

From plan B, the following times were measured:

Hour	11.25	11.45	12.45	13.45	14.45	15.45
Time (s)	8.50 9.4 9.40	(7.92) 8.19 8.01 8.05	8.37 8.64 8.32	6.66 6.88 6.84	9.27 9.22 8.59 8.64 8.73	5.94 6.25 6.52 6.25
Mean value (s)	9.10	8.08	8.44	6.79	8.89	6.24
Flow ($m^3 s^{-1}$)	0.00110	0.00124	0.00118	0.00147	0.00112	0.00160

- ➔ Mean value flow = 0.001285 $m^3 s^{-1}$ (values in parentheses were not included in the calculations)

Appendix 3

Pictures from field work in the Rio Rocha.

Pictures from sampling 1 – 9th of July, 2013

Puente de servicio de caminos in the Rio Rocha, water flows from the right (section A) to the left (section B). At this point in the river's flow is quite strong and the water is dirty and smells bad. In connection with the river there is a car wash, which means that both the water and chemicals used at the car wash goes directly into the river. There are also chickens in the area which means that their feces probably is present in the water.

Plants in the river at Puente Huayllni, pink/brown flowers and green leaves. Pictures from sampling 2 – 23th of July, 2013

Puente de servicio de caminos in the River Rocha.

Car wash close to the water at puente de servicio de caminos in Rio Rocha.


Puente Huayllni in the Rio Rocha.

Pictures from sampling 3 – 7th of August, 2013


Sampling from puente de servicio de caminos.


Puente huayllni.

Appendix 4
Pictures from the field work in the neighborhood.

Pictures from sampling 1 – 15th July 2013

Rio Rocha close to outflow A.

The area around outflow B.

The water of the Rio Rocha close to the outflow B.

Pictures from the work with ServiMaster – 17th July 2013

The hose is connected to the beginning of the septic tank.

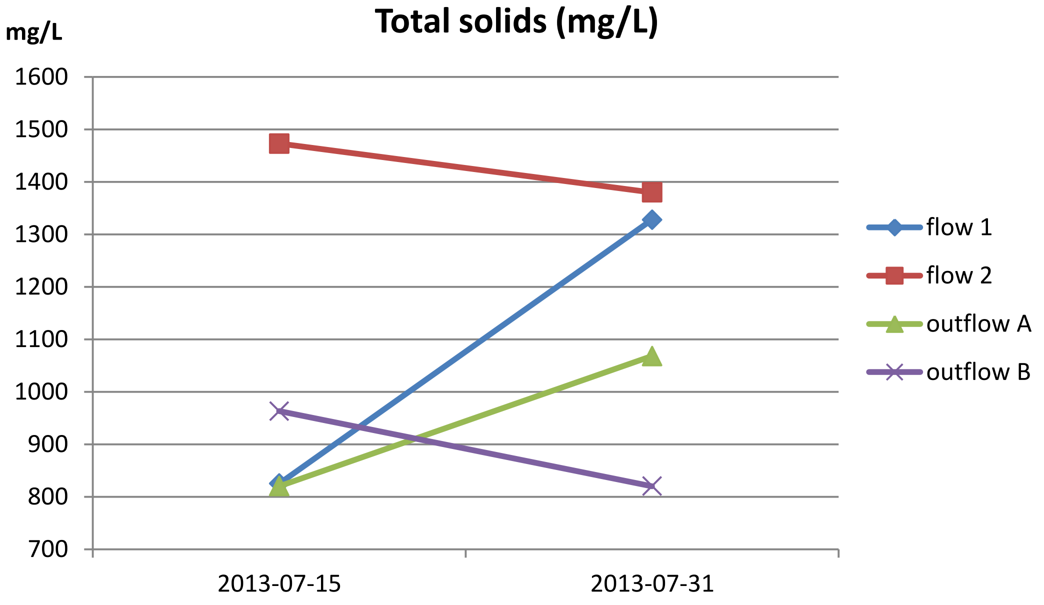
The ServiMaster truck with a capacity of $15m^3$.

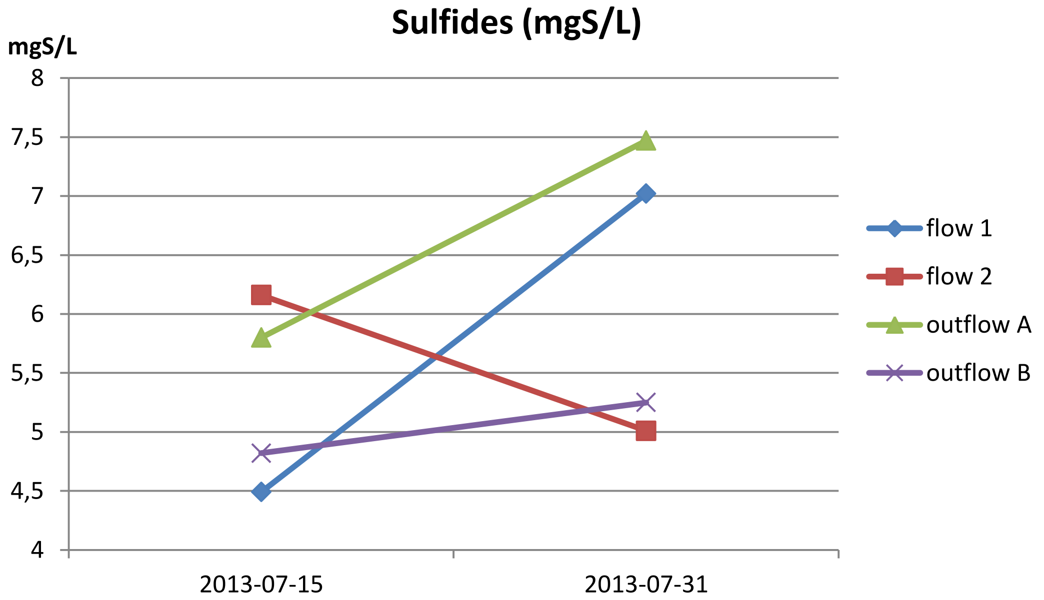
Pictures from sampling 2 – 15th July 2013

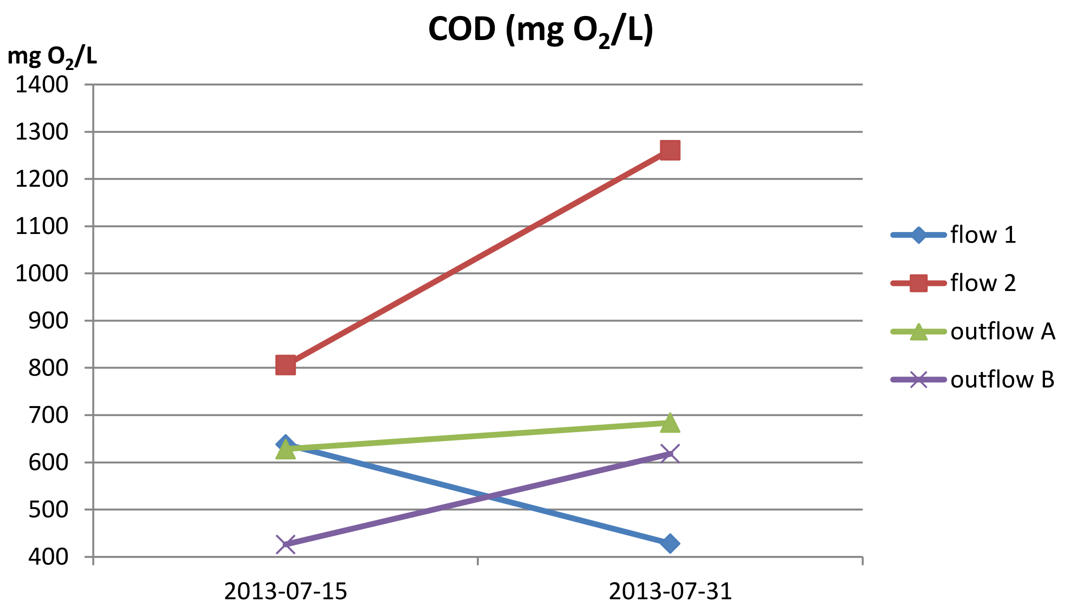
Very low water level at point 2.

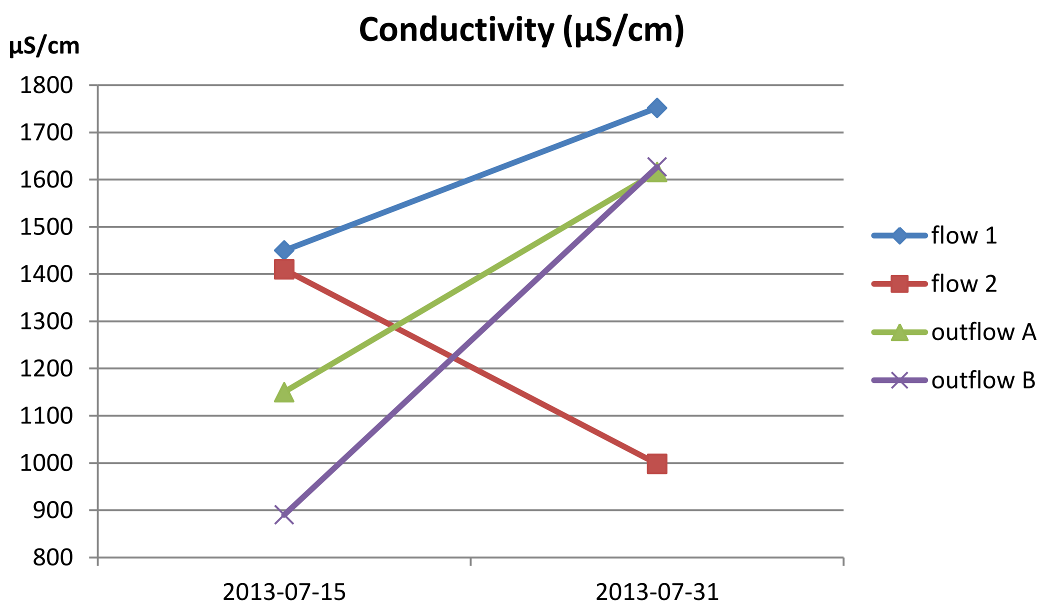
Appendix 5

Graphs that compare the concentrations of different parameters before and after the maintenance with ServiMaster.






COD (mg O2/L)
mg O2/L
1400
1300
1200
1100
1000
900
800
700
600
500
400
2013-07-15
2013-07-31
flow 1
flow 2
outflow A
outflow B


Conductivity (µS/cm)
µS/cm
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
2013-07-15
2013-07-31
flow 1
flow 2
outflow A
outflow B

Appendix 6
Wastewater treatment by Aguatuya.