CHALMERS

Assessment of Small-Scale Water Treatment Systems in the Amazonas

Bachelor thesis in Civil Engineering

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Preface

This report is written for the Swedish foundation Ancla who has contributed with much aid for the inhabitants in the Colombian part of Amazonas. The work with water treatment is fairly new started and lacks investigation concerning its function. This thesis is made to provide academic and technical inputs to their work. First of all we would like to thank Börje Erdtman for the original idea, on which this thesis is based, and for having confidence in us in conducting this study. Thanks also to Ingrid Brauer and Lennart Holm for invaluable help during implementation of systems and visits in communities. Your knowledge and experience has contributed with guidance when writing this report.

Thanks to Ann-Margret Strömvall and Sebastien Rauch for converting Börje's idea to a research question for this bachelor thesis and for being supportive and for contributing with tutoring during the entire project and for enabling our observation to be resented in a technical report.

Thanks to Yvonne Young who gave important guidance when applying for the SIDA funded Minor Field Study scholarship. Receiving this both allowed us to conduct an on-site study and enlightened the importance of sustainable development when working with technical challenges in developing countries. During the on-site study Ana Maria Tenazou, Jovino Mozambite Perez and Pilar de Ruiz provided much help before Ancla joined us in Leticia. Gratitude also to Ivan Herrera, for believing in our project, visiting us in Leticia and helping to start cooperation with the municipality. Your expertise and Spanish skills extended our understanding for cultural differences and knowledge of the system's maintenance and construction.

On-site water analyses were viable through help from Mona Pålsson who generously provided us with all laboratory material we asked for and contributed with knowledge even after returning home. Christer Larsson enabled bacteria testing by providing agar plates.

Without all your help, we would never have been able to perform this on-site study as wished and the report would not have reached the credibility as it now has.

Karin Blad and Jennifer Ringsby
May 22, 2013

Abstract

Access to safe water is a pressing issue in developing countries, especially in rural areas such as the Amazonas. Small-scale systems are generally considered to be good solution to this problem. This bachelor thesis is an assessment of two different small-scale water treatment systems implemented by the Swedish Ancla foundation and used by Indians around the city of Leticia the Colombian Amazonas. The aims of the thesis are to determine which system is most sustainable in the local context and provide guidelines and recommendations for the implementation of the system, as well as recommendation for the foundation's continued work in the region.

The two systems compared are based on sand filtration and essentially differ in capacity, with the first system constructed to provide water to a community group, while the second system is designed for household use. As this is a Minor Field Study the foundations of sustainable development – social, economic and environmental sustainability – have formed the basis for the comparison and led to the development of an evaluation framework with the following indicators: feasibility, economic sustainability, surrounding sources of pollutants, environmental impact and water quality. To reach a reliable and objective result each aspect was awarded a factor based on their importance for sustainable development and the two systems were compared considering these aspects.

The comparison shows that the larger system is preferable for most of the aspects, especially economic sustainability and feasibility. This system requires less sand per person connected; the sand is heavy and expensive to transport which makes the feasibility unsustainable. The fact that Ancla is entirely funded through private donations makes the economic sustainability especially important. However, the larger system does not provide water to household. Access to water in every family's house is a stated goal of international water development. If the Ancla Foundation desires to fulfil this goal, an alternative treatment method, such as ceramic filters or a more carefully engineered two-step system, should be investigated.

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1. Introduction

In the Amazon rainforest region, the access of water is good over the year (Jonsson, 2013). Heavy rains occur during the entire year but from December to May the rain is more common and the duration is longer. During this period, called the rain period, problems with water access are less frequent. The annual amount of rain is between 1500-3000 millimetres (WWF, 2013) and 50-80% of the humidity in central Amazonas comes from transpiration (Jonsson, 2013). Leaves and other plants produce water vapour, which form rain clouds in the atmosphere (ACEER Foundation, 2013). Due to this natural water cycle a major part of all water is bound in the area and is good preconditions for being able to install simple water treatment plants for the inhabitants.

A foundation working for increasing the living standards in the Amazon region is Ancla, founded by the Swedish man Börje Erdtman in 1993 (Ankarstiftelsen, 2013). Since then, he has achieved great success with construction of schools and water treatment systems. Ancla is characterized by their low costs, efficient way to work in close collaboration with the population and for entirely relying on volunteer efforts. The construction used for schools is unique and has, as the water treatment systems, been developed together with Swedish entrepreneurs who willingly have contributed with their knowledge.

Ancla started a water treatment program in 2010, but the first steps were taken already in 2006 when two Swedish students from Uppsala University developed the water treatment system, shown in Picture 1.1, referred to as "the plant", in a SIDA-funded Minor Field Study (Brauer, 2013). The water is led through four tanks and one stair placed between the first and second tank (Andersson & Erlandsson, 2006). The stair is for aeration, while flocculation and sedimentation take place in the second tank, and the third is for filtration. The fourth tank is for storage of the purified water. Ancla however, refers to this system as "three-step system", despite more purification steps involved. Andersson and Erlandsson wrote in their conclusion:

> 'To introduce a new method, like a water treatment plant, in a developing community with a different culture, is always connected with the risk that the method will not be maintained properly. But since Ankarstiftelsen are visiting the area, and this specific community, twice a year, and two inhabitants are made responsible, educated and given a salary for the maintenance of the plant, there is a great chance that the treatment plant will be kept used and well maintained.'

Ancla has invested many resources in teaching locals to run the three-step system (Erdtman, 2013). A motivated and driven person, from each community wanting a system, is chosen to take a training course in how to construct and maintenance a system and each participant receives the title "watermaster" (Brauer, 2013).

Since 2006, the three-step systems have been developed for simpler maintenance and construction (Brauer, 2013). The aeration and flocculation have been removed, which led to the "two-step system" shown in Picture 1.1. It is a small-scale water purification system containing only sedimentation and filtration and is customized to produce enough water for one household. It has been proposed that if the villagers can construct the systems by themselves, with some help from experts the first time, they will get a higher knowledge and interest in keeping them effective. The maintenance is believed to be easier if each family gets responsibility of their own system and trials of the systems are made by one of Ancla's employees, Ana Maria, in her community Puerto Rico.

Picture 1.1. Left: The three-step system built 2006 by Andersson and Erlandsson. Right: A two-step system next to the school in Puerto Rico.

When choosing recipient community several different aspects are taken into evaluation. The fundamental criterion is access to a sufficient water source and the Amazon River is not to recommend (Brauer, 2013). Water treatment systems are installed with following three conditions taken into consideration with the most crucial first. 1. If Ancla previously built a school in the community. 2. If the inhabitants show a great interest in getting treatment systems. 3. If they can provide their own watermaster.

An advantageous view to have when tackle these issues is to rely on the well-debated global goals for sustainable development. Sustainable development was first defined 1987 in the Brundtland Report as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). The World Conservation Union (IUNC) clarifies in their report 'The Future of Sustainability' from 2006 that Brundtland's idea has been the basis for the currently commonly used approach of the three dimensions environmental, economic and social sustainability, which often are illustrated in a Venn diagram, as in Figure 1.1, to show the importance of integration between the aspects (Adams, 2006).

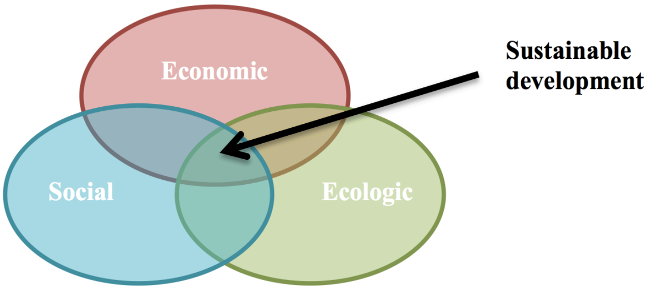

Figure 1.1. Sustainable development illustrated in a Venn diagram.

The Millennium Development Goals (MDGs) set out in 2000 says that by the year 2015 a halving of the proportion of people without access to clean drinking water will be reached and it includes actions like 'develop and implement efficient household sanitation system' and 'promote affordable and socially and culturally acceptable technologies' (UN, 2002). Clean water and sanitary has a vital impact on all eight MDGs and is a prerequisite to be able to fully achieve any of the goals (WaterAid, 2010).

The Global consultation on water states in the United Nation Development Group report from 2013 that the MDGs would not be fulfilled until 2015 and that a continuing sustainably managing of clean water is the security for both water and sanitation, production of food and energy as industrial development and over all healthy ecosystems (Lucarelli, 2013). In WaterAid's report 'A vision for water, sanitation and hygiene post-2015', published in March 2013, a vision of 'Safe and sustainable sanitation, hygiene and drinking water used by all' was stated with the following summary targets (Back, 2013):

> '1. Everyone has water, sanitation and hygiene at home.
> 2. All schools and health centres have water, sanitation and hygiene.
> 3. Water, sanitation and hygiene are equitable and sustainable.'

From 2006 to 2013, 79 households and 9 communities have received a water treatment system from Ancla (Brauer, 2013). Brauer expresses the vision for 2016 as:

> 'All communities along the Amazon River, from Letcia and 130 km upstream on the Colombian side, will have access to small-scale water treatment plants, at school and/or at home, in the end of year 2016'

The vision and goal conforms well to the three main goals outlined in WaterAid's report 'A vision for water, sanitation and hygiene post-2015'. To correspond well to these global goals, Ancla is in great need of a thorough evaluation of their two different systems.

1.2. Aim and purpose

The aim of this thesis is to implement and test the two-step system for small-scale drinking water supply and compare the technique, usability and sustainability with the three-step system. The result of the comparison will give guidance and milestones how to create a better drinking water situation in the region. Five different aspects listed below, aligned with the definition of sustainability, will be taken into account in the comparison.

Feasibility	Difficulty to get hold of necessary parts, the suitability of the construction for included purification mechanisms, the daily maintenance and cooperation with municipality and universities.
Economic sustainability	The fixed and variable costs of the construction and maintenance of the systems.
Surrounding sources of pollutants	Identification of activities that can pollute the water and soil in the area such as agriculture, active forestry, boat traffic, oil extraction and wastewater from communities upstream the rivers.
Environmental impact	Evaluation of the water treatment system's potential impact on the surrounding environment.
Obtained water quality	Identification of the water quality before and after running through the system. The quality has to be adequate safe for human use, but does not have to meet the standards of municipal drinking water.

1.3. Method for assessment of the systems

The study was done on-site in Colombian city Leticia during an eight-week period. To obtain knowledge of the construction and the mentality of the local people several interviews were made with the villagers where installations of new systems were made. Water was collected from different systems for analysis of the water quality and observations were done to get an as good overview as possible. To reach a concrete and objective result the aspects outlined in Section 1.2 are given a factor based on the question '*How important is this aspect to make a system sustainable in this region?* ' and the systems are scored on how well they meet these aspects. Based on these results alternative methods are described in section 4.7.

1.4. Limitations

Although this thesis has been carefully prepared and only treat the five aspects outlined in the aim and purpose, there are a few unavoidable limitations within the aspects as listed below.

Feasibility

The only water treatment plants treated in this report are Ancla's two systems and possible alternative treatment methods, if the discussion points towards this. The sub-aspect cooperation is delimited to cooperation with the municipality in Leticia and Universidad de Santander in Bucaramanga.

Economic sustainability

The economy will be treated based on the current methods and costs when installing new systems. The only costs included are the actual and measurable costs. Therefore alternative costs, such as what the family's time could be spent on if not having a system to take care of and vice versa, are excluded.

Surrounding sources of pollutants
Only brief comprehension of existing sources of pollutants will be made in this study. No literature studies of how and how commonly the landmark is used for agriculture and forestry and what sources of pollutants come from these will be made.

Environmental impact
The impact of the systems will be delimited to the direct impact of installation, usage and dismantling of the system. Impact from the plastic tanks, tubes and chemicals when manufactured are excluded.

Obtained water quality
Because of the difficulty to do laboratory analyses in Leticia, all laboratory studies have been done with simpler field methods. Since the possibilities to bring large amounts of reagents and deionized water from Sweden were limited, as qualitative tests as possible, with the laboratory tools available were conducted on selected treatment systems. The results will only be indications for evaluations and are not planned to serve as an overview of the water quality in the area.

2. Small-scale systems for drinking water treatment

This chapter presents three small-scale water treatment systems. In the first section, the two- and three-step systems used by Ancla are more specifically described. The second section presents an alternative, more efficient two-step system and the third section briefly describes ceramic water purification. These alternative treatment methods and the possibility to implement them in Leticia are further outlined in section 4.7.

2.1. The two- and three-step systems

The two systems are based on the same purification methods; sedimentation and slow sand filtration, also called biosand filter. The three-step system also uses aeration and flocculation for more efficient water purification as the quality of the source water varies.

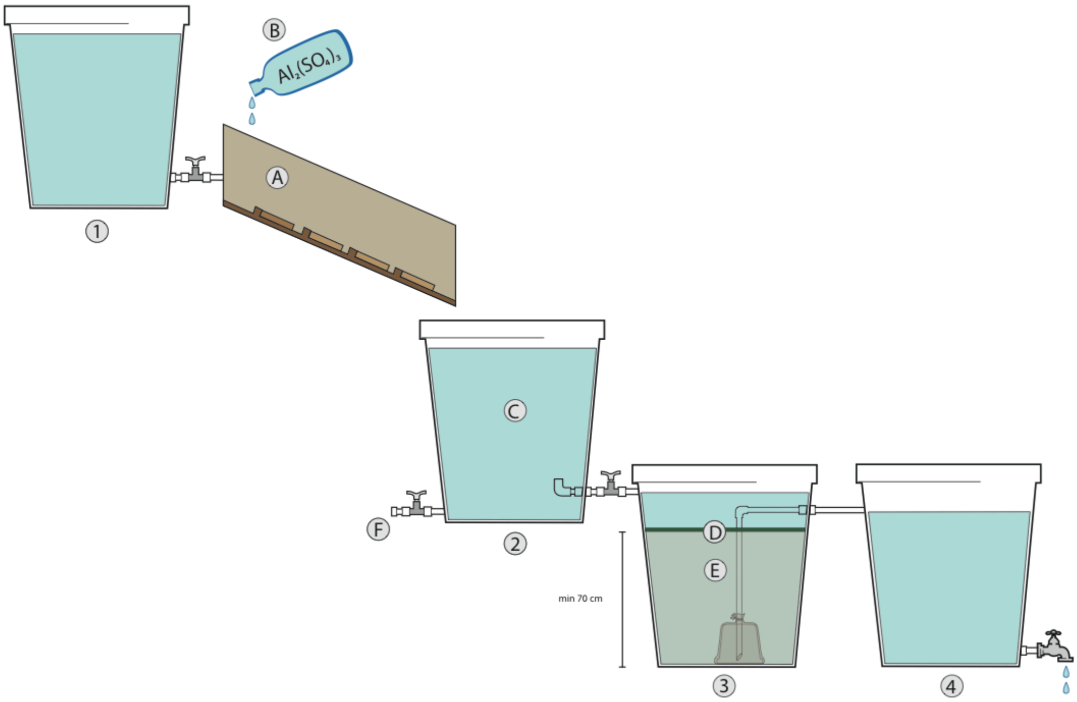

Figure 2.1. Illustration of the three-step system

A – Aeration
B – Flocculation
C – Sedimentation
D – Biological degradation
E – Sand filtration
F – Emptying of sediment

2.1.1. Function of the purification mechanisms

Tank 1 is only for collection of water, either from rainfalls or from a local source. When Tank 1 is filled, the water is led through a stair, constructed to create a turbulent flow and aerate the water (B), which changes the chemical structure of the particles and make them precipitate (Cittenden et al, 2005; Wikipedia, 2013). At the outlet of Tank 1 a solution of aluminium sulphate, $Al_2(SO_4)_3$, is added continuously as the water flows and mixes into the water. This solution increases the particles ability to settle by removing their repellent chemical charge and make them flocculate (A) (Ives, 1991; Pizzi, 2010). When all water is led to Tank 2 the water is left undisrupted for four to five hours when the gravitation separates particles from the water by settling (C) to the bottom of the tank (Thureson, 1992). Thereafter the water is led to Tank 3, which is filled with minimum 70 cm of sand (NDWC, 2000). In the top layer of the sand, a biological filter called "schmutzdecke" (D) is created in which particles gets biologically degraded (Logsdon, 2008; Keeley et al, 2005; Hookea & Morris, 2003). The schmutzdecke is expected to be able to remove up to 96% of the faecal coliforms (Fewster et al, 2004). It is of greatest importance that the schmutzdecke is covered with water at all times as effectiveness of the bacterial degradation will stop if the sand gets dry (NDWC, 2000). The sand also contributes with mechanical separation (E) of particles (Logsdon, 2008). When the purified water has passed the sand filter a filter cloth covered bucket separates it from the sand and the water is led to Tank 4 for storage. The pipe leading the water from Tank 3 to Tank 4 has to be drained 1 to 8 cm above the sand level to prevent dehydration (Anonumous, 2011). Continuously the sediment collected in Tank 2 has to be emptied (F).

The two-step system is, as shown in Figure 2.2, built from Tank 2 and 3 and only includes the purification mechanisms C, D and E.

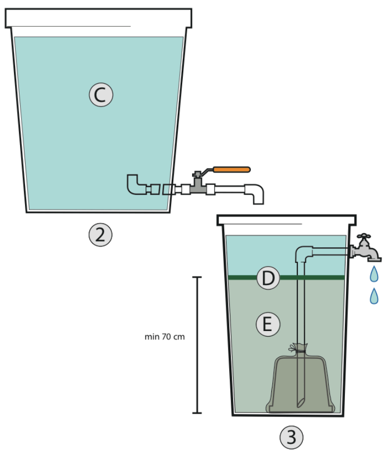

Figure 2.2. Illustration of the two-step system
C – Sedimentation
D – Biological degradation
E – Sand filtration

Tank 3 currently used in the two-step system has a diameter of 0.58 m and a 0.264 m^2 area. The diameter of the three-step system is 1.10 m and the area 0.949 m^2.

2.1.2. Flow rate

The maximum flow, Q, through 1 m^2 sand should be 150 l/h, a vertical speed of $4.167 \cdot 10^{-4}$ m/s, to keep a good degradation of particles in the schmutzdecke and decrease the amount of particles filtrating deep into the sand (Jonsson, 2013). Exceeding this flow might clog the sand filter and decrease the efficiency that would lead to the need for rinse or change of the sand.

The area of the sand filter determines the amount of produced water. The area required for one person is calculated by $A_{person} = \frac{1.1 \cdot C}{Q \cdot h}$, where C is the daily consumption of water, h the hours a system operates per day and Q the maximum flow. A 10% factor of safety is used for the water consumption to avoid running the system at its maximum capacity.

The daily production for supplying one family of eight members with potable water from a two-step system is 40 litres (Tenazou, 2013). This gives a daily consumption of five litres per person and day. The diameter needed for Tank 3 for supplying x people is calculated by $d = 2\sqrt{(A_{person} \cdot x)/\pi}$.

2.2. Development of the two-step system

The system shown in Figure 2.3 is a development of the two-step system. Tank 2 contains more than 200 litres and the diameter of Tank 3 is adapted based on the calculation of the flow rate. A tube with proper dimensions for providing a household is suitable if sealed in one end and can buried in the ground for stability. Gravel can be used in the bottom of the sand to prevent the sand from entering the water pipe (Hofkes & Huisman, 1983). In addition a filter cloth is placed between the sand and the gravel. To ensure a constant flow the outflow from Tank 3 should be open at all times. The purified water is collected in Tank 4, which is a smaller bucket provided with a tap and a lid.

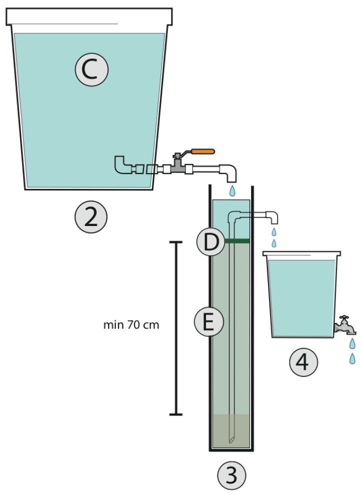

Figure 2.3. Illustration of the new two-step system

C – Sedimentation

D – Biological degradation

E – Sand filtration

2.3. Ceramic filters

One alternative to sand filtration for household usage is ceramic filters which have been used since the late 1980s for purifying water. Originally most of the filters were produced commercially, which made them too expensive for people in developing countries (Hunter, 2009). Since then the technique has been developed and it is now possible to make filters with simple methods. Today the filters are referred to as the best household water treatment method, mainly because the filters are cheap, durable, easily maintained and do not need any chemicals to produce water of good quality (IDE, 2006).

2.3.1. Construction and properties

The filters are mostly formed as pots, which are placed in, or connected to, a collecting vessel for storage of the purified water (Hunter, 2009). The pots are made from a mix of clay, water and other organic material that is dried and fired and results in a porous matter that is permeable to water (Hunter, 2009). The porous structure of the filters (Ciora & Liu, 2003) can remove particles smaller than the smallest disease-causing bacteria (Lister, 1996). The filters capacity to remove bacteria is therefore good but the effect on viruses is more uncertain. Clay mixed with iron or aluminium oxides before firing has proven to be effective to remove viruses (Hunter, 2009).

Figure 2.2. A cross-section of a ceramic water filter (Hunter, 2009)

To prevent mould and algae from growing on the filter the pot can after burned be dipped in a silver solution, which also helps kill bacteria (Wikipedia, 2013). Ceramic filters are relatively slow and produce between 1-3 litres per hour, a capacity that decreases with time because of accumulation of impurities on the filter surfaces (Stauber et al, 2008).

2.3.2. Efficiency

The efficiency of ceramic filters is, seen to turbidity and bacteria, sufficient. In a study made in rural Bolivia one type of ceramic filter reduced the amount of thermo tolerant coliforms (TTC) with 100%. The diarrheal disease risk decreased with 70 % for individuals older than 5 years and 83 % for children younger than 5 years (Clausen et al, 2004).

3. Method and experimentation

The field study was performed in the surrounding region of the cities Leticia and Puerto Nariño. The small communities included in the comparison are located up to 130 kilometres upstream the Amazon River from Leticia and along the tributary Rio Loretoyaco.

Because of the diversity in the nature of the aspects, different methods have been used. Laboratory instruments, receipts and logbooks were all used, but due to the complexity and lack of time for making thorough studies in all categories, a predominant part of the study was based on the author's perceptions and observations. Figure 3.1 shows a flow chart for assessment of the two-step (2S) and three-step (3S) methods for small-scale drinking water supply.

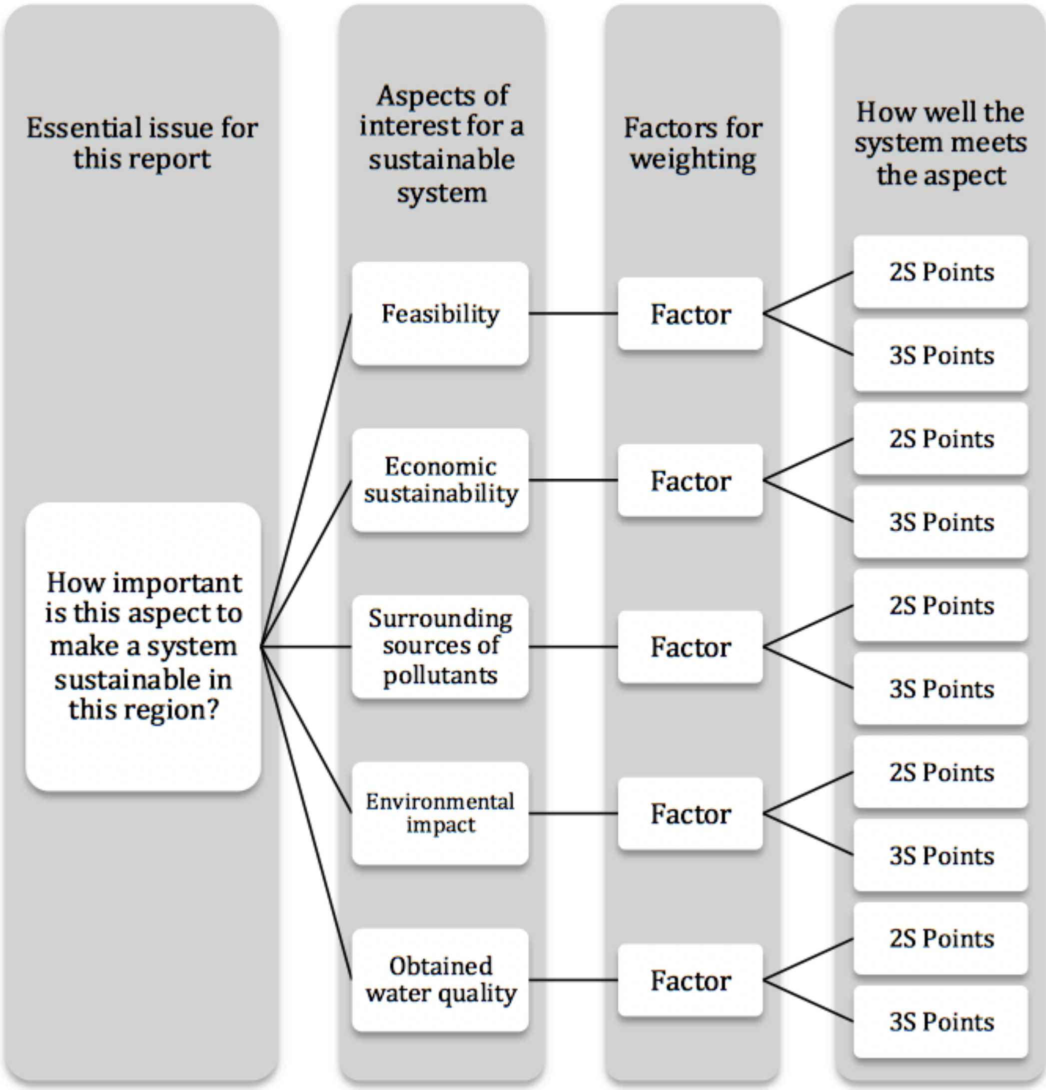

Figure 3.1. Flow chart of the method.

3.1. Method for comparison and weighting

The five aspects chosen for this study are extensive and to make the final results as objective and specific as possible a weighting matrix was used. All aspects are given a factor in the scale 1-5 based on how important they are in terms of sustainability. The two systems were then graded in how well they fulfil the different aspects.

The factors of the aspects were, as shown in Figure 3.2, multiplied with the points of each system. The sum of these points were divided with the highest total points for a percentage that answers the question 'How well does each system fulfil the sustainability goals?'.

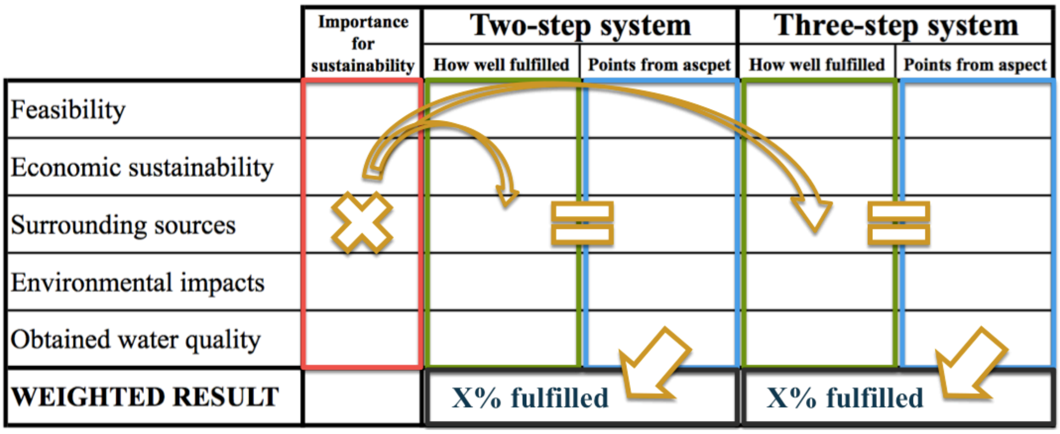

Figure 3.2. Description for calculation of the results.

3.2. Feasibility

This aspect is divided into the four sub-aspects supply of materials, construction, maintenance and cooperation. They are altogether important for the feasibility and if one ore more of them miss, a construction of such a system is not to recommend.

Supply of materials

All material needed was bought from two different shops in Leticia. Information of all parts needed to construct one system was written as an excel document that permitted entering an optional number of systems for providing a shopping list. The list was used to simplify and avoid misunderstandings when purchasing new material.

Samples from two different sand sources, a natural source close to the community 12 de Octubre and a building store in Leticia, were collected and brought to Sweden for investigation of the suitability for sand filtration. This was made by determination of the grain size distribution with the method described in Appendix 1.

Construction

During the project 39 two-step systems and one three-step system were constructed. When they were built a few important milestones were detected both from own experiences and by observing the villagers attempts to imitate instructions. The dimensions of the systems were verified with the calculations of the flow rate presented in section 2.1.2.

Maintenance

To get an idea of how the systems should be maintained, discussions were held with Ancla. Their documents of the maintenance have been observed and double-checked with new researches.

Cooperation
To get a sustainable maintenance of the implemented systems, a well working cooperation is preferable, not only with the villagers, but with the municipality as well. During the three last as well as this year, Ancla has held annual meetings with the department for water treatment at the municipality of Leticia, called Plan Agua.

The associate professor Ivan Herrera from the Universidad de Santander in Bucaramanga, UDES, was connected to the project to have an academic contact in Colombia. By a visit to Leticia and meetings with Plan Agua cooperation between Plan Agua and UDES hopefully could be established.

3.3. Economic sustainability

When evaluating the results of the economic sustainability a comparison of the fixed and variable costs of the two- and three-step system has been made. The fixed costs include the costs of materials and transportation to construct one system and the variable costs are monthly costs for chemicals, gasoline, maintenance and collecting of water samples for laboratory. The bases for these values are receipts of material and transportations and historical transactions. The current production of the systems, as well as the amount of villagers, is taken from Ingrid Brauer's compilations made for Ancla.

The economic sustainability was treated by answering the question 'How many months after the installation would the costs of the two- and three-step systems be equal?'. Equation 1, where x is the amount of months, was used to compare the two-step system (2S) and the three-step-system (3S)

$$amount\ 2S\ for\ one\ 3S\ \cdot fixed\ 2S + variable\ 2S \cdot x = fixed\ 3S + variable\ 3S \cdot x \qquad (1)$$

Since the production capacity of the two systems was different, the fixed costs were weighted to the amount of consumers and production capacities by calculating the amount of two-step systems needed for one three-step system.

3.4. Surrounding sources of pollutants

The possible sources of pollutants and land usage were observed both from the long-distance transportation boat going along the Amazon River and Rio Loretoyaco and the visits in several communities along these rivers. Studies of regional maps were the basis to explore possible nature reserves that might affect and restrict the overall usage of the land. Meetings with Plan Agua also provided some knowledge on this subject.

3.5. Environmental impacts

All elements or procedures included in the construction of the two- and three-step system were evaluated with respect to their possible effect on the environment. Detected threats were analysed with respect to the impact on animals, including the human, and the environment.

3.6. Obtained water quality

In the laboratory study five two-step systems and three three-step systems were included, from which samples were collected and brought to Leticia for testing. The temperatures when sampling differed between 25°C and 32°C. The sample collection method developed during the project but the final approach was to collect one sample each from Tank 2 and 3 and if existing, Tank 1. These were compared to determine the efficiency of each purification step. For more detailed description of the sampling, see Appendix 2.

The parameters of interest for the analyses of the water were pH, conductivity, oxygen, nitrate, nitrite, ammonium, iron, colour, turbidity, alkalinity, calcium and chloride and bacterias. For determination of these a HACH DR/890, a MultiLine P4 together with one pH electrode, one D. O. probe CellOx 325 and one TetraCon 325® were used as well as two different Hanna instruments methods and a set for titration. Agar plates were used for testing the amount of bacteria. Deviations are described in Appendix 3.

4. Results and discussion

In section 4.1 – 4.5 the field study results are presented and discussed based on the five aspects. The concrete results when using the method described in section 3.1 are presented in section 4.6 and followed by motivations for the factors and points given.

4.1. Feasibility

This chapter is divided into the four sub-aspects. The aspects will be treated separately in the result and the weighting.

Supply of materials

All parts needed for the construction are available in Leticia or the neighbour city Tabatinga. The range of products is not wide, but sufficient for the existing construction. If constructing large amounts of systems in a shorter time some parts might run out of stock. Therefore a careful planning is demanded as well as good contact with the building stores.

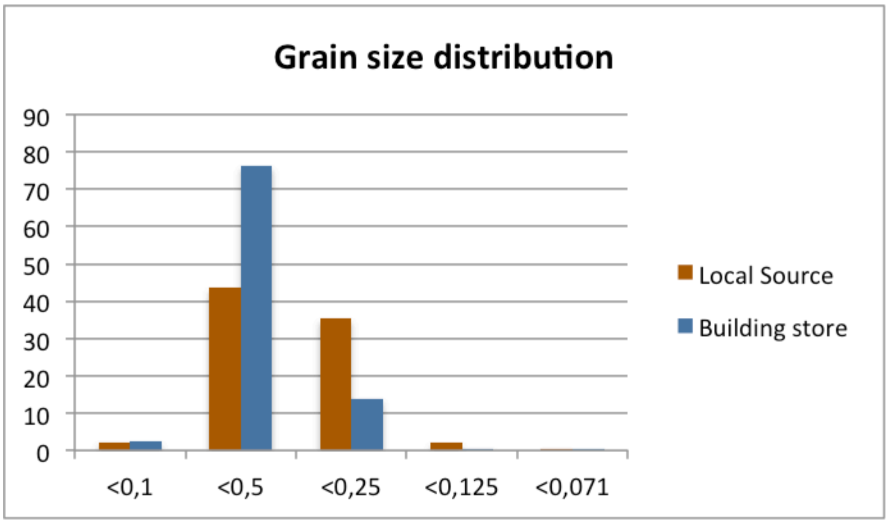

Figure 4.1. Diagram for the distribution of sand grain sizes.

The sand tests showed that the two different sand sources provide sand with different quality. As shown in Figure 4.1, the sand from the natural source contains more varying grain sizes than the sand bought in the building store. The effective size for filter material is 0.15-0.35 mm and therefore the material passing through the 0.125 mm sieve is not to prefer to have included in the sand (NDWC, 2000). An immeasurable amount that passes the 0.25 mm sieve will be under the limit of 0.15. This should disappear by the wind when sieving the sand on-site in the communities. Such a procedure is highly preferable to go through before every installation of a new system, but it takes some planning.

The sand from the natural source is easy to access during the dryer season when the river water level is low. During rainy season however, the sand has to be collected from the bottom of a tributary, as shown in Picture 4.1, which comes with a few disadvantages. Finding suitable sand with low amounts of biological matter is difficult, one person has to be willing to collect sand while standing in the river and the collected sand will be wet and has to be dried to allow sieving.


Picture 4.1. Collection of sand from a natural source.

Construction
It is of greatest importance that rainwater covers the filter cloth covered bucket in Tank 3 to prevent the bucket from breaking when the sand is added. The outflow from Tank 3 must be placed on the right height to protect the schmutzdecke and create the requested flow. To make the adhesive able to stick, all relevant parts of the tubes have to be polished from flakes after sawing and external soil. The waterproof adhesive tape has to be rolled on to the threads in the right direction and gaskets have to be included in the right place of the construction. If using sand from the local source it has to be checked carefully to ensure it does not contain biological matter or clods of mud (Thureson, 1992). The stair of the three-step system has to be constructed with a sufficient slope to create the turbulent flow.

The constructions and the milestones for a proper installation of the systems are fairly equal. The difference is the amount of people affected if errors are detected and the system has to be taken out of service for maintenance. Therefore the importance of an initially correct design is higher for the three-step system, why only a well-trained person should build the systems.

With calculations from the flow rate, the two-step system with eight consumers should, for a maximal use, have an area of 0.0123 m^2 and the three-step system with 240 consumers, an area of 0.370 m^2. These results are 4.67 % and 39 % respectively of the current sizes. Based on this information the two-step system is found to be oversized, why a development of this system is presented in section 4.7. The three-step system current area is thus sufficient for supplying 615 people with water if used perfectly, but both the low population in the communities and a too difficult maintenance makes this impossible.

Maintenance
Ancla disclaims liability for the two-step system after submission to the families. They will be responsible for running the system properly, cleaning the schmutzdecke and replace broken parts, a problem noticed to be rarely occurring probably as the consumers are few. Half of the 32 systems in the community Puerto Rico were detected to be out of function, a problem that can be explained by that the users' lack

of knowledge in the function. Interviews made it clear that not even Ana Maria, the person responsible for these systems, knows how to solve these problems.

The daily maintenance of the three-step system is done by the local watermaster. His job includes running the system twice a day, providing required water and empty Tank 2 from sediment. The major problems detected among the watermasters are incomplete sedimentation and functionality of the pump. The systems are often constructed adjacent to schools where the usage of playful children lead to broken parts, problems supposed to be reported by the watermaster and then fixed by Ancla's employed. When this reporting has been absent, the systems have been out of function for longer periods.

To ensure an acceptable quality of the water produced and to detect decreases in efficiency, continuous laboratory test are preferable for detecting if enhancing action is necessary or if the watermaster misunderstood important steps of the purification. This quality control Ancla does not propose for the two-step systems.

Cooperation

Ancla has equipment for testing water parameters such as pH, turbidity, nitrate and bacteria and one of Ancla's employees has been responsible for performing these tests. Unfortunately the tests were not performed correctly resulting in false information of the water quality. Also the person currently responsible for monitoring the systems lacks experience for doing a satisfying job, why cooperation with professional local organisations is preferable.

Ancla has proposed that if they continue constructing systems that produce water with acceptable levels of chemical and biological parameters, Plan Agua could be responsible for the monitoring over the year. As Ancla had problems with their own water analysis, the best would be to let Plan Agua implement collaboration with a local laboratory that can prove that the systems are well functioning.

The associate professor Ivan Herrera from UDES, offered Plan Agua tutoring with the laboratory analyses. Both methods and parameters of interest, evaluation of received results and overall being a source of security for the on-going work. Such cooperation would increase the quality of the implementation of small-scale water treatment systems and make them sustainable, when all knowledge is reachable within Colombia.

4.2. Economic sustainability

For the three-step system the transportation cost was estimated from the knowledge that one system is built in two days, every transport costs 3,500 SEK and that one pre-visit is needed, from which the cost is divided over seven other villages being inspected the same day. For the two-step system, estimation was made of how many of the total number of boat trips dedicated to the 24 systems constructed along the river in 2013.

The costs for laboratory sample collection from the two- and the three-step systems are equal since the collection is done the same day with the same boat and employee. For this reason this cost is independent of the amount of systems and will be eliminated in the comparison.

Table 4.1. Calculus for the costs of the two- and three-step systems.

Two-step system (2S)		**Three-step system (3S)**	
Number of consumers	**8 people**	**Number of consumers**	**240 people**
Production	**40 l/day**	**Production**	**2000 l/day**
Material cost	1 600 SEK/system	Material cost	8 200 SEK/system
Sand	230 SEK/system	Sand	1 000 SEK/system
Transportation	656 SEK/system	Transportation	7 500 SEK/system
		Pump	10 000 SEK/system
		Watermaster	380 SEK/month
		Gasoline	200 SEK/month
		Chemicals	10 SEK/month
Fixed costs	**2 486 SEK**	**Fixed costs**	**26 700 SEK**
Variable costs	**0 SEK/month**	**Variable costs**	**590 SEK/month**

With the values from Table 4.1 along with Equation 1 and the fact 30 systems are needed for one three-step system seen to the number of consumers. Calculation based on this shows that first after 6 years and 8 months the cost of the two-step systems are equal to one three-step system. This indicates that there is a large economic surplus when building one three-step systems instead of several two-step systems.

4.3. Surrounding sources of pollutants

The part of Amazonas where the field study was conducted holds several different nature reservoirs, which are highly restricted by rules for what kind of activities that are allowed (Áreas Protegidas con Ecoturismo, 2013). Gold mining, oil extraction and large-scale deforestation are forbidden and agriculture and plantation only occurs for personal use. This makes the identification of the different sources much easier as the above-mentioned pollutants have been excluded from this assessment.

The Amazon River is high trafficked and the area around Leticia is no exception. Both upstream and downstream Leticia big cities are located. These major cities are connected with both public transports as well as trade traffic and many of the engines used are old and contribute to large amounts of impurities. The inhabitants use a special type of long tail engine, locally called Peki-Peki, which is a reconstruction of a regular two-stroke engine (Perez, 2013). As the two-stroke engines are often old and not designed for water usage, large amount of gasoline flows through unburned (Skärgårdsstiftelsen & Havs och vatten myndigheten, 2013) and they also miss catalysts, which causes large emissions of CO_2 (Wikipedia, 2013). When gasoline discharges into the environment some of it immediately evaporates, the chemical substance dissolves in the water and some parts catches onto the ground (Vermont Department of Health, 2011). Inhalation of gasoline vapours irritates the lungs, causes headache and is damaging for the nervous system if inhaled over a long period of time.

The major source of pollution is nonetheless wastewater from the cities and communities upstream the rivers. This water contains high amounts of chemical and biological substances poisonous to both environment and people (Naturvårdsverket, 2013). Iquitos and Leticia lacks wastewater treatment despite their large population (Gonzalez Reyna, 2013) and applies on all of the smaller Indian communities along the rivers. The municipality is however planning to construct wastewater treatment in connection to Leticia.

When comparing the different surrounding sources of pollutants it becomes clear that most of them are a result of widespread poverty in the region. People do not have the possibility to buy environmentally friendly engines or take proper care of their waste. The majority of the inhabitants are minority populations whose needs and rights unfortunately have been overlooked in the past (Vanegas, 2009). Allowing oil extraction and deforestation has been more profitable for decision-making politicians and improvements on inhabitants living conditions have been second priority. There are no rules to construct proper wastewater treatment when individuals construct new houses, which lead to the fact that every community discharge their wastewater untreated. The same problem applies to the cities. The government has until today not taken any responsibility for improving the situation.

4.4. Environmental impacts

The aim of the project is to construct sustainable water treatment plants and to achieve this it is important to map the system's potential environmental impacts. If this is done properly deficiencies can be detected and corrected before harming the environment. The fact that the communities included are located in the sensitive Amazon rainforest makes this aspect even more relevant.

When installing new systems boat transports are made and contribute with sources of pollutants in the system's source water, which creates a bad circle with the effects from gasoline emissions described in section 4.3.

By planning each boat trip and coordinate the transports the amount of emissions can be reduced. To give the beneficiaries proper education and ensure that they have the right motivation before receiving a system would reduce the need for monitor and reparation.

The aluminium sulphate that accumulates in Tank 2 is emptied in the environment. Aluminium is toxic to water living organisms and have harmful long-term effects on the water environment (Fisher Scientific GTF AB, 2013). Finding a good storage of chemicals should be prioritised rather than stop using them and by burying the sediment in the ground, the risk of children getting access to the chemicals is eliminated. The ground mostly consists of clay with low permeability, which prevents the pollutants from reaching the water streams (Figueiredo, 1995).

It is vital to handle of the sediment in the communities due to the lack of proper disposal management in Leticia. Even if Leticia could provide this, leaving the disposals there would not be recommended as the distances between the communities and Leticia are long. The transportations would stand for a bigger source of pollution then the sand itself.

Spare parts generated during installation, when holes are made in the plastic tank sticks into the muddy ground and are therefore difficult to remove. Some tanks have to be opened with a saw and contribute to the problem as well. Tank 4, where the purified water is stored, is black and when heated by sunlight poisonous substances from the plastic might be released (Christiansson, 2012). Plastic tanks are though affordable, accessible and suitable for tropical climate and their light weight makes them easy to transport, which makes the advantages higher.

Colombia has a much lower ecological footprint than the Western world, but the living standards differ a lot in the country (Wikipedia , 2013). The inhabitants in the affected area represent a very small part of the total consumption in the country, which must be taken into consideration when analysing the systems' environmental impact. To provide potable water is of bigger importance than stop using them because they possibly pollute the environment.

4.5. Obtained water quality

Results were obtained on most of the tested parameters but are for some parameters scarce and can only be used for indications of the relation between time, maintenance and produced water quality. The system B is the only system tested over time as the method was not completely determined from the start of the project. Tests performed continuously from the installation and two months ahead are the only method resulting in correlations between the parameters. All test results are presented a table in Appendix 5 and illustrated in diagrams in Appendix 6.

4.5.1. Analysis of laboratory results

Chloride was measured from the five first samples with the low range method. All result was lower than five ions per litre. The assumption that the content of chloride was this low all through the region and for this reason without possible impact on the humans was made. No sources of salt additions were identified and possible chlorine contributors such as municipality water treatment plants do not exist in the relevant areas, why it was concluded to be out of interest to proceed testing throughout the continuing study (WHO, 2003).

Visible colour of the water produced seems to be an indicator of problems with the maintenance and when this is the case the consumers chose not to drink the water. The system told to be the best in one community was seven years old and produced crystal clear water, but analyses of the quality showed that the amount of substances increased in most of the measured categories after running through its sand filter. Assumption can therefore be made that visible colour is the only way the consumers can tell the quality of the water.

None of the samples are close to exceed the recommended values for nitrate and nitrite in drinking water, which are 10 mg/l and 1 mg/l respectively (USEPA, 2012). Four of the five systems showed an increase after passing through the sand and continuous tests of these parameters could be indications of how the systems were or should be maintained, but are not a reason for taking actions as they are not a threat to the human health (WHO, 2007).

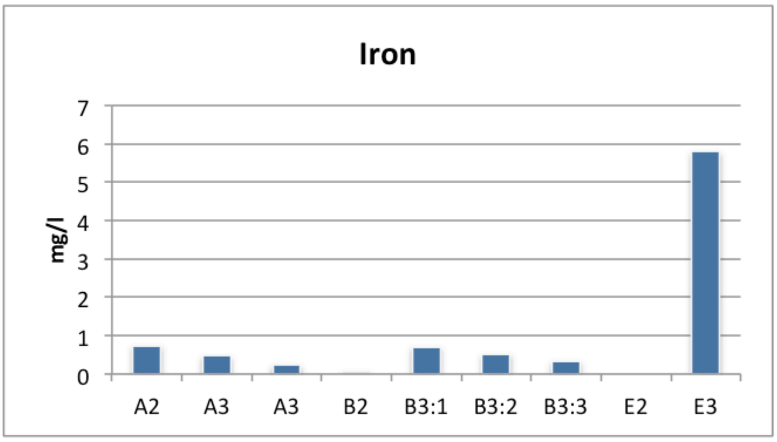

Figure 4.2. The results of the iron tests in system A, B and E.

The amount of iron in the produced water varies from 0.0 mg/l to 6.0 mg/l, which is a quite high value in drinking water but not dangerous to the health (WHO, 2003). A decrease of iron shows that the system operates as it should. The increased levels might depend on the origin of the sand and this theory is shown in system B and E. They contain sand from the same local source, which contained clay lumps that might be the explanation to the increased iron levels. System B was recently installed and had at all three test higher values after passing the sand. In system E iron increased from 0.0 mg/l to 5.8 mg/l and as the samples were collected in plastic bags it is hard to find another explanation than that iron from the sand had dissolved in the water. The same pattern can be shown in the re-installed H system, where new sand was added.

System A, which uses sand from the building store, deviates from the results above and has a decreased content of iron after passing the sand, a result that might be misleading. System B and E would probably decrease the amount of iron if using source water of the same quality.

System B and E clarifies that the addition of ammonia probably comes from the sand. In the first test of system B the amount of ammonia was relatively high. With time the amount decreased gradually which shows that rainwater probably rinses the sand. The same observation was made in system E, which had been out of use for an uncertain time. This system got an increment from 0.0 mg/l to 0.21 mg/l ammonia after running through the system. An increase of any parameter after filtering is never advantageous but in these cases the amounts do not oppose a threat to the health (WHO, 2003).

Aeration of water has a positive effect on the amount of iron (Tekerlekopoulou et al, 2006) and ammonia (Stratton & Jamieson, 2003). The three samples from system B were performed over time and show in Figure 4.3 that the amount of iron and ammonia decrease simultaneously as the oxygen increase. However as shown in Appendix 5, the oxygen in the water from system E is higher than in system B but in this case no positive effect on the iron and ammonia value was detected. This might be explained by the fact that system E has been stagnant.

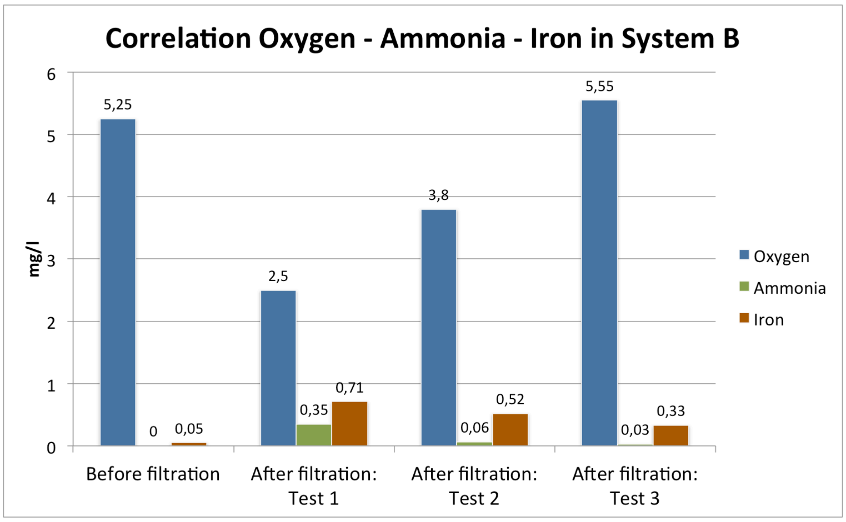

Figure 4.3. Correlation between oxygen, ammonium and iron in system B.

It seems preferable to run the system carefully with rainwater right after the installation and continue with this until the schmutzdecke is created and the water quality is ensured. After this, studies show that the systems are sufficient to clean water from other sources as well (Hunter, 2009). Turbidity is the amount of dissolved particles per water unit (Peavy, 1985) and in system B it points towards the conclusion that rainwater probably cleans the sand. Usage of rainwater is however believed to slow down the creation of the important biological degradation layer. The schmutzdecke was not visible in any of the three-step systems. Two explanations to this are the current flow of 1000 litres in 1.5 hours, which is 444 % above the recommended and observations of that a previously construction enabled the filter to run dry. Two of the two-step systems were as shown in Picture 4.2 observed to have a visible schmutzdecke and prove that the current flow and construction is functioning.

Picture 4.2. Two-step systems with visible schmutzdecke.

The fact that, as shown in Appendix 5, many parameters increases after passing the sand could be an indication that consuming rainwater directly is preferable. Important to keep in mind when making this conclusion is the absence of results on the bacteria levels. Bacteria are a big threat to the human health (Forsberg, 2007) and the most decease causing is coliform (Fewtrell & Kaufmann, 2005). They originate from human or animal faeces and give an indication on whether the water has been exposed to faecal contamination or not, but in tropical climate coliform bacteria can live on their own, which makes the contamination source difficult to determine (Wikipedia, 2013). The bacterial degradation taking place in the schmutzdecke is therefore the most crucial for the purification. The varying amount of rain also leads to stagnant water in Tank 4 where bacteria start to grow.

4.6. Comparison and weighting

The results presented in Table 4.2 are motivated in section 4.6.1 and 4.6.2. The method for this comparison led to that the two-step system reach 56% of a sustainably excellent system, while the three-step system reaches 85%. As the result for the two-step system is insufficient, consideration of reconstruction or a replacement, such as the ceramic filter, should be made. The result for the three-step system is however satisfying, but the flow rate should be corrected for an improved water quality.

Table 4.2. The results of a sustainability assessment of small-scale water treatment systems.

	Importance for sustainability	Two-step system		Three-step system	
		How well fulfilled	Points from ascpet	How well fulfilled	Points from aspect
Feasibility	**4,75**	2,88	13,66	4,13	19,59
Economic sustainability	**5**	1	5	5	25
Surrounding sources	**2**	5	10	4	8
Environmental impacts	**1**	4,5	4,5	4,5	4,5
Obtained water quality	**3**	4	12	4	12
WEIGHTED RESULT		**57%**		**88%**	

4.6.1. Determination of the aspects importance for the comparison

Below each aspect is described and assigned a number between 1 and 5, where 1 is not important at all and 5 is very important. The sub-aspects of feasibility will be given sub-factors that are added for an average value.

Feasibility

Supply of materials

The supply of materials is important for a sustainable construction. If one part is not available in the closest cities, they have to be imported. There are no roads leading to Leticia, why everything would have to be transported with expensive air cargo or brought by the Swedish team once a year. These are no sustainable solutions for reaching independence in the long-term.

Sub-factor: 5

Construction

The construction of the system needs to collaborate with the existing purification mechanisms and this has to be secured before implementation in communities. This is essential as the systems are founded by donations.

Sub-factor: 5

Maintenance

In order to make the system work over a longer period of time a proper maintenance is of great value. If not correctly maintained, the risk that the system produces water with lower quality than the source water itself is high and if that happens the

investment is wasted. It is essential that the implementation of laboratory tests works well otherwise faults will be undetected and result in consumers becoming ill.
Sub-factor: 5

Cooperation
Collaboration is essential for a long-term sustainable implementation of small-scale water treatment systems, but until the construction is optimized and the government has decided to supply all citizens with potable water, the water situation in this region relies on Ancla's efforts. Having a National University providing expertise and tutoring on a local level would increase the chances to make the water situation sustainable.
Sub-factor: 4
The average factor: 4.75

Economic sustainability
The economic aspect is highly relevant for a sustainable system. Today, much effort is put on collecting money from Swedish donors and an efficient use of this money is vital. To get confidence in the actions made would generate the basis for the continued work with finding new donors. The responsibility of an economically viable system is easier to hand over to the municipality.
Factor: 5

Surrounding sources of pollutants
A water purification system is only needed if the surrounding water is not clean enough to drink untreated. Surrounding sources of pollutants become less relevant as rainwater or water from a carefully chosen source.
Factor: 2

Environmental impacts
The environmental impact of the systems is important to take into consideration to create a sustainable system. However the inhabitants have a small ecologic footprint and potable water is a basic necessity. Providing this might be of higher importance in this early stage of their technical development than the potential environmental impact of the methods used.
Factor: 1

Obtained water quality
When introducing water treatment plants in developing countries, the goal is not to produce water with the standards of municipality treatment plants. An improvement of the human health when consuming treated water instead of source water is demanded.
Factor: 3

4.6.2. Determination of how well the two- and three-step systems meet the aspects
The motivations for the systems in Table 4.3 are a summary of the most important results from the study. The points are on the scale 1 and 5, where 1 is not fulfilled at all and 5 is very well fulfilled.

Table 4.3. Comparison of the performance of two- and three-step systems.

	Two-step system	**Three-step system**
Feasibility	Supply of materials All constituents are easy to get hold of in Leticia. The amount of sand is large and implies expensive and difficult transportations if not taken from local source. *Sub-points awarded: 3.5*	Supply of materials All material is available in Leticia and the amount of sand needed, with respect to the amount of people provided, is low. *Sub-points awarded: 5*
	Construction The principles of the two-step system are suitable for the purification mechanisms. Some improvements could still be made. *Sub-points awarded: 4*	Construction The current construction of some of the systems does not collaborate with all of the purification mechanisms. *Sub-points awarded: 3*
	Maintenance It is necessary to convey the importance of a proper maintenance to all users. The maintenance is easy if they fully understand the construction, but language barriers make it difficult to achieve. *Sub-points awarded: 3*	Maintenance If a suitable watermaster is found for the daily maintenance the system have all conditions for being perfectly maintained and well functioning. *Sub-points awarded: 4.5*
	Cooperation The fact that every household needs their own system, a hand over of the responsibility to the municipality is too extensive. *Sub-points awarded: 1*	Cooperation A submission of the responsibility to the municipality, for one or two systems per community, is possible to implement. *Sub-points awarded: 4*
	Average points awarded: 2.88	**Average points awarded: 4.13**
Economic sustainability	In terms of the cost efficiency in relation to both the amount of consumers, sand and the quantity of the produced water this is not a sustainable system. **Points awarded: 1**	In relation to the amount of people provided, the system is profitable. **Points awarded: 5**
Surrounding sources of pollutants	The only water used is rainwater and no airborne pollutants occur. **Points awarded: 5**	As water from other sources than rainwater is used, the surrounding sources of pollutants are relevant. Due to the natural reservoirs in the area the risk of finding heavy pollutants decreases. **Points awarded: 4**
Environmental impact	During the time the system is in use, the effect on the surrounding environment is zero. The low amount of consumers and produced water, in respect to the constituents and sand, is unsustainable. **Points awarded: 4.5**	The only factors with environmental impact are aluminium sulphate and gasoline. However, their impact compared to the high amount of consumers is low. **Points awarded: 4.5**
Obtained water quality	The construction of the system is suitable for the source water and some systems also had a visible schmutzdecke. If maintained correctly it has all chances for producing water of good quality. **Points awarded: 4**	Due to few reliable test results this aspect has been hard to analyse. The design of the system along with information from watermaster indicates an adequate water quality. **Points awarded: 4**

4.7. Alternative methods for household water supply

Below, two alternative methods for the two-step system are presented and evaluated based on the same matrix as the previous comparison and the opportunity for implementation in the concerned area. The assessment is only made for presenting the alternatives and the results are assumptions to achieve a value in how the system might function and work as supervision for Ancla in their coming decisions.

4.7.1. Development of the two-step system

The two-step system should run for 24 hours a day and its dimensions could be optimized with calculations of the flow rate in section 2.1.2, and gives $A_{person} = \frac{1.1 \cdot 5}{150 \cdot 24} = 0.00153$ m^2. The diameter needed for Tank 3 is calculated by $d = 2\sqrt{(0.00153 \cdot x)/\pi}$ and would for the two-step system, with x = 8, give the required diameter of 0.125 m instead of 0.58 m.

All constituents are available in Leticia and the transportation is easy as the amount of sand is relatively small. The current construction of the two-step system does not allow a constant water flow, why the design is changed. By using gravel the risk of breaking the bucket in the bottom is eliminated. The maintenance is equal to the two-step system, but will be easier to perform as the adapted dimensions simplify the cleaning of the top sand layer and Tank 2. Due to the problems detected with the two-step system, monitoring of an employed is needed until the systems function optimally, a need difficult to manage because of large amounts of systems. The system could be run on either rainwater or source water.

4.7.2. Ceramic filters

The construction of ceramic filters is simple and all material is available in Leticia. None of the constituents are expensive or have an environmental impact except from silver that can be excluded as all source water is of relatively good quality. The filters have to be transported from Leticia to the communities, but as they have a small volume and are light-weighted many people can be provided with one transport. No monitoring is needed as the only maintenance is keeping the filters clean from algae. Ceramic filters are not known to be accessible in Leticia and if so, a small factory for manufacture should be started. A realization could enable the government to provide all families that live outside the cities with ceramic filters.

4.7.3. Assessment and weighting of the new two-step system and ceramic filters

The new dimensions of the two-step system decrease the amount of sand to only 4.65 % of the current, which significantly improves the economic sustainability and the feasibility.

Table 4.4. Calculus for the costs of the new two-step system and the ceramic filter.

New two-step system		**Ceramic filters**	
Number of consumers	**8 people**	**Number of consumers**	**8 people**
Production	**40 l/day**	**Production**	**40 l/day**
Material cost	650 SEK/system	Material cost	245 SEK/system
Sand and gravel	20 SEK/system	Transportation	100 SEK/system
Transportation	220 SEK/system		
Fixed costs	**890 SEK**	**Fixed costs**	**345 SEK**
Variable costs	**0 SEK/month**	**Variable costs**	**0 SEK/month**

In Table 4.4 the new two-step system has been calculated with the same estimations as the two- and three-step systems. The costs of 45 SEK per ceramic filter are based on data from International Development Enterprices and the plastic bucket for colletion of purified water is estimated to 200 SEK. The transportation cost is based on that 16 new two-step systems and 50 ceramic filters could be included in one transport. Along with Equation 1, the costs of the new two-step system and the three-step systems are equal. The ceramic filter is much cheaper and first after two years and four months the costs are equal with the three-step system. However, the cost for implementation of a factory has to be added and split on all ceramic filters. Therefore the costs of the new two-step system and the ceramic filters could be assumed fairly equal.

Table 4.5. The results of a sustainability assessment of the alternative small-scale household water treatment systems.

	Importance for sustainability	**New two-step system**		**Ceramic filters**	
		How well fulfilled	**Points from ascpet**	**How well fulfilled**	**Points from aspect**
Feasibility	**4,75**	3,13	14,84	4	19
Economic sustainability	**5**	5	25	5	25
Surrounding sources	**2**	4	8	4	8
Environmental impacts	**1**	4,5	5	5	5
Obtained water quality	**3**	4	12	5	15
WEIGHTED RESULT		**82%**		**91%**	

The results of this rough study are presented in Table 4.5 and shows that ceramic filters are, as expected from the theory, the best alternative for a sustainable use of small-scale water treatment systems. The reason for not being 100% is the current lack of filters in Leticia. Due to the optimization of the dimensions the new two-step system is much better than the current, but the amount of material needed per person and inability to create collaboration still makes it inferior the three-step system.

5. Personal reflections

This thesis was performed in Colombia. Receiving a Minor Field Study scholarship from SIDA enabled us to do this project and make it become indescribably much more than just a thesis leading to a Bachelor degree and providing access to master programmes at Chalmers. Going abroad and living in another culture for eight weeks was an experience that provided much more than if the study had been made as a literature study from Sweden. First of all, the result would never have reached the extent and credibility it has now. The experience has also enabled us to learn how to approach an ethnic group totally different from us Westerners and hopefully reach sustainable development with the help of Swedish resources. This has been a project where we have been able to follow the meaning of the famous quotation ‘Give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime’.

It was the contact with Ancla that first made us come up with the idea of going to Amazonas and study water treatment systems. Worth to mention is that the project from the beginning had a different approach than what is presented in this report. The founder of Ancla, Börje Erdtman, has 20 years of experiences of working in the region and he was convinced that focusing on development of the two-step system towards the women would be the best approach for reaching a successful project with reduced occurrence of diseases among the children. We have tried to work in line with his believes, but the observations and calculations have forced us to deviate from his idea and adapt a new perspective. We do yet agree with his conviction, but with a more sustainable system than the current two-step system.

If turning back the time was possible, we would have ensured that we had learnt some Spanish before departure. The fact that this was the only language spoken caused many misunderstandings, inability to convey the right knowledge when working with the villagers and find out how the systems were maintained, what kind of source water that was used and identification of the errors when a system proved to be out of function. We would also have tried to determine the method of sampling to have better strategies for receiving accurate results, especially as the conditions excised with all laboratory equipment.

This project has not only included a real trip to a developing country far away from safe Sweden, but has also been a year of a mental travel. We are both two individuals continuously searching for new challenges to make our time more qualitative. Therefore this project has not only been a school project that had to be done before a deadline, but a lifestyle for us since the ideas first took shape. Everyday day we have put loads of effort for making this project as successful as possible and making so has been easy and come naturally as we are passionate for the subject. Today we are a part of Ancla as members of the water team, a foundation that has reached great success with all investigations ever made. Therefore we are sure that this project will contribute with a difference for the people in the Colombian part of Amazonas.

6. Conclusions

There are a few direct conclusions to make from this study. Ancla should continue their work implementing water treatment in rural areas of the Amazonas. Until a proper alternative to the two-step system, such as the new two-step system or ceramic filters, is available priority should be placed on the three-step system. An interpreter is essential for an accurate transmission of how the construction and the maintenance should be done for a sustainable use of the systems. All three-step systems should be built in pairs to enable larger maintenance of one system without affecting the villager's health. A lid, a fine net or fabric should cover the tanks to prevent biological particles from entering the water. Tank 4 should, if possible, be placed in the ground to keep the water cold. If sand from a local source is used it should be collected during the dry season sieved before installation. After installation the system should be run on rainwater to rinse the sand from possible pollutants before actual use. Water from other sources should be used after the schmutzdecke is created. To secure the production of the schmutzdecke, water should flow from Tank 2 to Tank 3 at all times and the flow rate in the three-step system should be decreased. To enable this, a new schedule of an optimized operation should be created. The positive effect of the aluminium sulphate wins by a large margin over the negative effect on the environment and with the low costs included there is no doubt of using this in every system. A pit for putting the sediment in should be excavated in the vicinity of the system. The positive effects of higher turbulence in the water make it preferable to develop the aeration in both systems. Sampling should always be made on water from both before and after filtration to determine the efficiency. If the amount of tests is limited it is more useful to concentrate the tests to a few systems through time than testing all. Since no parameters measured were in the reach of dangerous for the human health efforts should be put on developing the bacteria tests. Oxygen, ammonium, iron and turbidity are interesting for continued testing since they give indications of the condition of the sand and the schmutzdecke.

Clean water is a basic human need and access to clean water is therefore considered a human right. Rural areas in developing countries, including in the Amazonas, are often lacking proper treatment facilities. The implementation of the treatment systems presented in this thesis provides an opportunity to improve the living conditions of rural communities. Further studies of the alternative household methods presented in this report should be made to improve the access to clean water and work towards the global goals.

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Attachments

Appendix 1 – *Method for sand test*
Appendix 2 – *Collections of samples*
Appendix 3 – *Deviations from the original method*
Appendix 4 – *Detailed method*
Appendix 5 – *Laboratory results*
Appendix 6 – *Diagrams of results*

Appendix 1

Method for sand test

The sand tests were performed in a laboratory and two different methods were used. First, the sand was sieved through a net of 2 mm and what passed through was placed in a 1 litre cylindrical plastic tube. 300 ml of deionized water and 200 ml of 0.05 M sodium pyrophosphate was added to the tube and placed in a turning device for 15 minutes. Thereafter 500 ml deionized water was added. With a screen plate the content was stirred and a hydrometer was, just when finished, placed in the water surface. The value (in g/l) was observed with the intervals of 0, 0.5, 1, 2, 5, 10, 20 and 50 minutes. The tube was emptied from the water and the sand was placed in an ovenproof form and placed in an oven of 105 °C for 24 hours for drying. Then the sand samples were placed in a stack of sieves with the sizes 2.0, 1.0, 0.5, 0.250, 0.125 and 0.071 mm. The stack was placed in a shaker for 15 minutes and the weight of the grains stacked in each sieve was measured.

Results for sand test

	Local source	**Building store**
Test with sieves		
Weight before test	*83,5*	*93,5*
<0,1	2,25	2,31
<0,5	43,53	76,2
<0,25	35,27	13,9
<0,125	2,05	0,57
<0,071	0,42	0,2
Test with hydrometre		
Weight before test	*103,3*	*100,1*
0	10	14
0,5	7	7
1	7	7
2	7	7
5	7	7
10	6,5	7
20	6,5	6,9
50	6	6,5

Appendix 2

Collections of samples

The samples were taken from different two- and three-step systems in five different communities along the Amazon River and Rio Loretoyaco. They were collected at different dates and the time between the collection and laboratory differs between a few minutes to 31 hours. All systems have different criteria and are therefore not easy to compare without take all aspects into account. Below the different criteria for every two-step system and three-step system are listed. The names written italic are equal with those in the result tables.

System A was installed in late 2012 and run on water from the river in the harbour in Leticia and sand from the building store. Totally one sample was taken from the first tank and two from the second tank. Between the second and the second sample from tank two it was noticed that sedimentation had not been properly done. All other two-step systems only run rainwater in their systems all throughout the year. System B was installed 2013 and used sand from their local source. Totally one sample was taken from the first tank and three from the second, where the first sample was taken directly after the installation while rainwater not yet had run through the system. In 2006 system C was built and since then the sand has never been changed, but has a green cover on the top of the sand. Totally one sample was taken from each of the tanks of this and the following two systems. System D was installed in 2011, the sand was changed six months ago and a small amount of the top sand was then saved to the new system for a quicker creation of the biological skin. The installation of E was made 2012 and never maintained since then.

System F was installed in 2006 and uses aluminium sulphate. It is usually run twice a day and uses both rainwater and water from a source close to the village, depending on the availability. Two samples were collected from here, one from the tap 50 meters beyond the system and one from their source. The system G was installed in 2010 and only uses water from Rio Loretoyaco drilled from a pump had some problems with the maintenance before the two samples were taken from the first and third tank. System H was first installed in 2011 but before the three samples were taken from the first, second and third tank, and the system had been reinstalled with new sand and filtration technique. When arriving for the collection of samples, the system had since the relaunch run on only water from their source except from the day before, when rainwater was used and the system run dry because of a perceived smell from the villagers. The system was run again with source water from the second tank, which had settled for three hours. After ensuring the water leaving the sand was the water from the second tank, one sample was collected from tank one, two and three each.

Appendix 3

Deviations from the original method

The HACH DR/890 equipment unfortunately only worked the first week, which is why colour could not be tested. Conductivity was only measured with reasonable results in the first half of the project because of problems with the equipment.

The original method of performing the collection of samples was shown to be too simple to get reliable results. The first idea was to compare the produced water from two three-step systems and three two-step systems several times during the project to detect changes over time. When time went by it became clear that a detection of the efficiency of the systems was more interesting. The first idea was to perform only one test from each kind of water source such as rainwater and water from a river or other source, and compare the results with the produced water. First in the last week the final approach of testing the water quality was reached. Of this reason there was not time enough to make such a thorough study as originally desired and this has led to that the results are difficult to make general conclusions from.

The sample collection of the two-step systems was planned to be done from a random selection of the 32 systems located in the community Puerto Rico to get a as statistically good basis for the evaluation as possible. All systems were, by the responsible woman Ana Maria, told to be well functioning, but when the collection was made many of the systems were shown to be out of function. Ana Maria did not know how the majority of the systems were cared and without this information the analysis would be useless. The selection was based on the systems she knew and from these a conscious choice of as different systems as possible, with respect to time and existence of maintenance, was made. Totally three systems were chosen from Puerto Rico and one from the neighbour village 12 de Octubre.

The four two-step systems had different preconditions. System B was installed one month before the sampling. System E was one year old and never maintained while B was two years old and maintained six months before the sampling. The C system was seven years old and never maintained, but told to be the best in the community. All system collected rainwater from metal roofing.

Also included in the study was one system on the small island Fantasia next to the harbour of Leticia. This system, A, was installed by Ancla as a test of two-step systems efficiency on purifying river water. The family that run A was told never to use any other water source than the river and the importance of letting the water settle for at least five hours. Tests were made on this system with nine days interval. At the first test the final method was not invented why only a test from the third tank was taken. The only observation made from the third tank was that the water on top of the sand was transparent indicating that the sedimentation had probably had good effects on the purification. At the second sampling this water was non-transparent and assumptions of that the sedimentation had not been adequate were made.

The agar plates were wrapped in plastic and stored in a fridge to prevent dehydration of the active lactose bacteria culture as the test were not planned to be performed until a few weeks later. Unfortunately all plates got contaminated despite the sealed plastic.

Appendix 4

Detailed method

HACH-LANGE
For detailed method descriptions of the test, see " the HACH instructions book", which comes along with the instrument. All reagents mentioned below are for one test, demands two sample cells and if nothing else is mentioned only the water sample is used for the tests. Nitrate (Low Range; 0 to 0.50 mg/L NO3--N) was tested with one NitraVer 6 Nitrate Reagent Powder Pillow and one NitriVer 3 Nitrit Reagent Powder Pillow. Nitrite (Low Range; 0 to 0.350 mg/L NO2--N) was tested with one NitriVer 3 Nitrite Reagent Powder Pillow. For Nitrogen, Ammonia (Salicylate Method; 0,01-0,5 mg/L NH3-N), two Ammonia Salicylate Powder Pillow, two Ammonia Cyanurate Reagent Powder Pillow and deionized water were used. Iron (Total; 0 to 3.00 mg/L) was tested with one FerroVer Iron Reagent Powder Pillow. Colour (Apparent; 0 to 500 units) as well as Turbidity (0 to 100 FAU) was tested with deionized water.

MultiLine P4
pH was tested with the pH electrode connected to the instrument. To determine highest accuracy, the electrode is put into WTW technical buffer solutions, first in pH 7.0 and second in pH 4.01 (at 25°C). The calibration programme was used if the results differ from the expected. The pH electrode was kept in a solution of KCl. Oxygen was measured with the D. O. probe CellOx 325 connected to the instrument. The sponge in the breaker must be moist with the solution OxiCal® - SL. The TetraCon 325® was connected to the instrument to measure conductivity and for calibration a control standard solution 0.01 mol/l KCl was used.

Hanna instruments
Calcium was measured with the HI 38086 Calcium Test Kit for Irrigation Water. All instructions, materials and reagents follow the kit, but some more deionized water for diluting of the samples might be necessary. Chloride was measured with the HI 3815 Chloride Test Kit. All instructions, materials and reagents needed followed the kit. Due to the low concentrations of chloride in the samples, only the Low Range (0 to 100 mg/L Chloride) was used.

Titration
Alkalinity was tested by using a 25 ml burette filled with 0.02 M hydrochloric acid (HCl). 3 drops of mixed indicator containing Bromocresol green, Methyl red and Ethanol was added to a 50 ml sample of the test, placed in a conical flask. Slowly HCl was titrated into the conical flask until the colour changed from light green to grey with a trace of red. The colour had to remain for 30 seconds not to continue the titration. A range between 3-10 ml of HCL was a good measure.

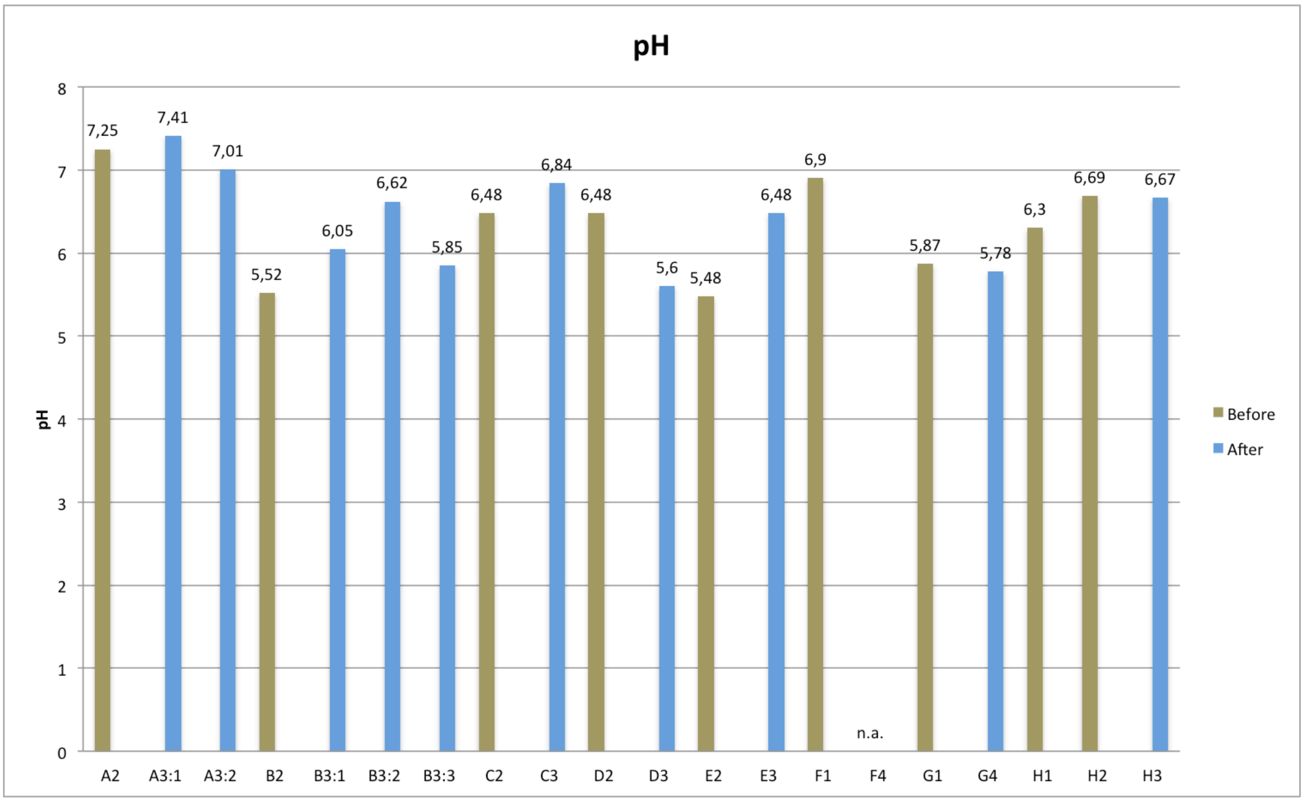
Appendix 5

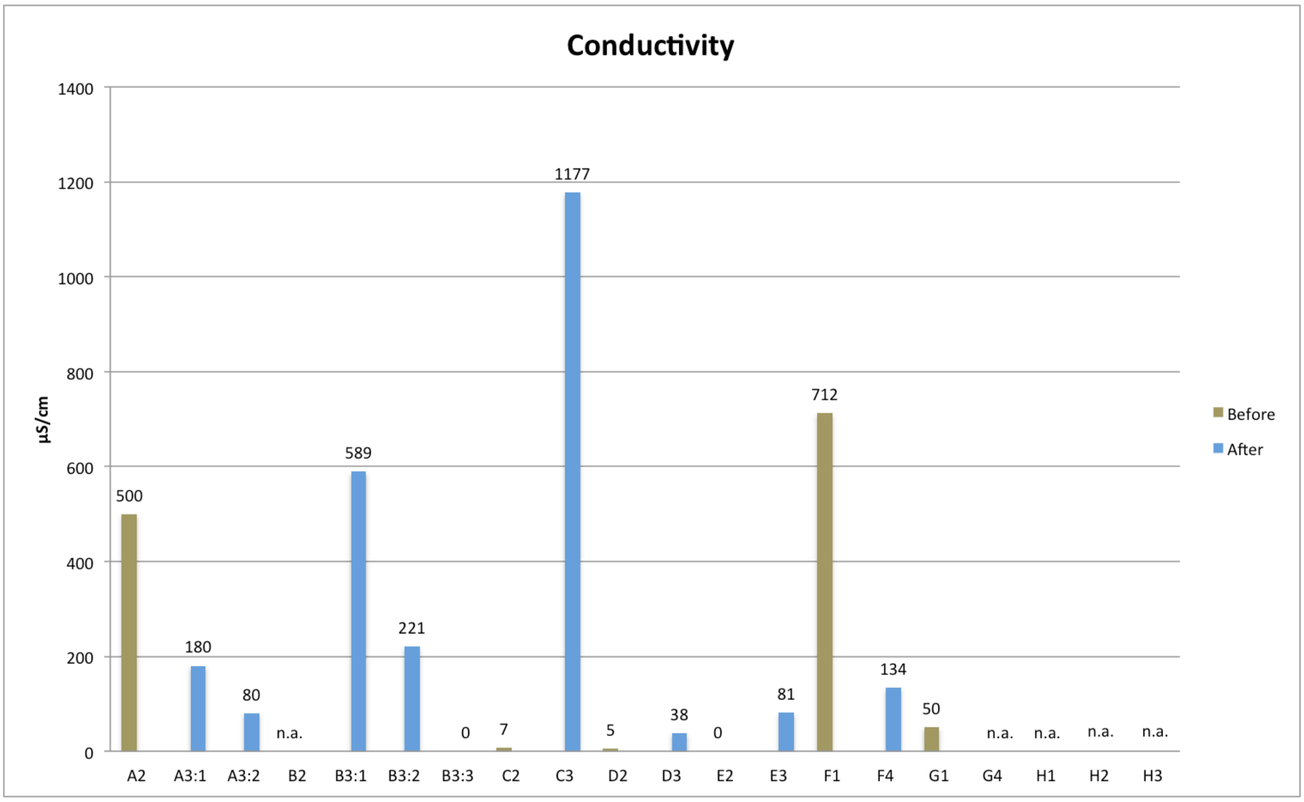
Laboratory results

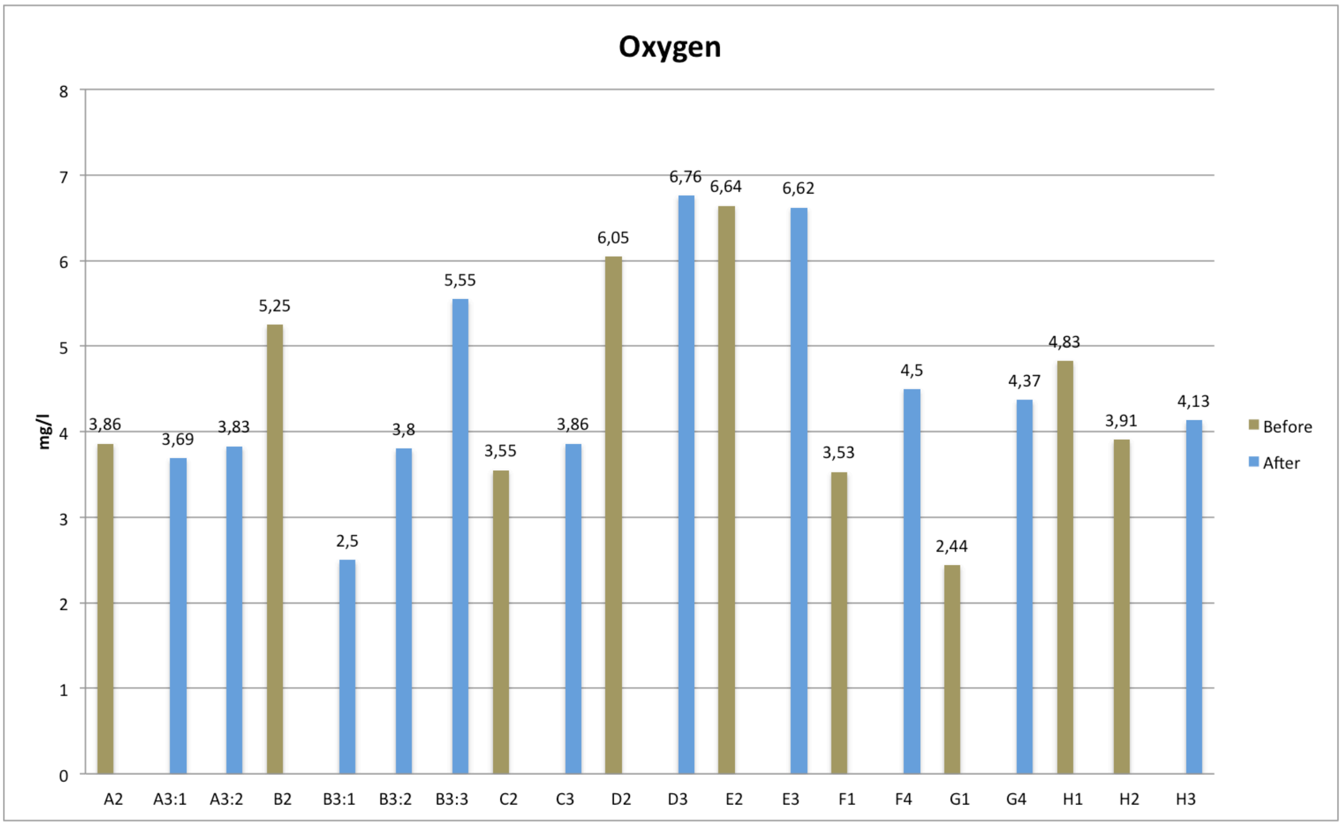
Tank	System	Community	Date	pH	Conductivity [µS/cm]	Oxygen [mg/l]	Nitrate [mg/l]	Nitrite [mg/l]	Ammonium [mg/l]	Iron [mg/l]	Turbidity [FAU]	Calcium [ppm]	Alkalinity [mM/l]	Colour [Pt-Co]	Chloride [pcs]
2	Two-step	Fastasia	2013-02-11	7.25	500	3.86	0.01	0.003	0.04	0.74	29	33	1.04	n.a.	n.a.
3	Two-step	Fantasia	2013-02-02	7.41	180	3.69	0	0.02	0.18	0.47	12	64	0.14	175	<5
3	Two-step	Fantasia	2013-02-11	7.01	80	3.83	0.02	0.003	0.02	0.23	15	34	1.08	n.a.	n.a.
2	Two-step	12 de Octubre	2013-02-17	5.52	n.a.	5.25	0.01	0.001	0	0.05	0	<7	<0.04	n.a.	n.a.
3	Two-step	12 de Octubre	2013-01-12	6.05	589	2.5	0.55 L	0.031	0.60 L	0.71	35	10.5	n.a.	n.a.	5
3	Two-step	12 de Octubre	2013-02-17	5.85	0	5.55	0.06	0.011	0.03	0.33	0	<7	<0.04	n.a.	n.a.
3	Two-step	12 de Octubre	2013-02-07	6.62	221	3.8	0.02	0	0.06	0.52	13	<7	0.06	n.a.	n.a.
2	Two-step	Puerto Rico	2013-02-07	6.48	7	3.55	0.02	0.004	0.03	0.02	3	<7	0.1	n.a.	n.a.
3	Two-step	Puerto Rico	2013-02-07	6.84	1177	3.86	0.05	0.006	0.03	0.32	8	<7	<0.04	n.a.	<5
2	Two-step	Puerto Rico	2013-02-17	6.48	5	6.05	0.01	0.001	0.01	0.11	6	<7	<0.2	n.a.	n.a.
3	Two-step	Puerto Rico	2013-02-17	5.6	38	6.76	0.06	0.006	0.01	0.02	1	<7	<0.2	n.a.	n.a.
2	Two-step	Puerto Rico	2013-02-17	5.48	0	6.64	0.01	0.009	0	0	3	<7	<0.04	n.a.	n.a.
3	Two-step	Puerto Rico	2013-02-17	6.48	81	6.62	0	0	0.21	5.8	33	<7	0.44	n.a.	n.a.
1	Three-step	Puerto Triunfo	2013-02-05	6.9	712	3.53	0	0.007	0.04	1.62	28	<7	0.36	n.a.	<5
4	Three-step	Puerto Triunfo	2013-02-05	n.a.	134	4.5	0.04	0.006	0.01	0	5	9.9	0.26	n.a.	<5
1	Three-step	12 de Octubre	2013-02-11	5.87	50	2.44	0.02	0.001	0.06	1.24	15	<7	0.4	n.a.	n.a.
4	Three-step	12 de Octubre	2013-02-17	5.78	n.a.	4.37	0.02	0	0.01	0.64	17	<7	<0.2	n.a.	n.a.
1	Three-step	Progresso	2013-02-17	6.3	n.a.	4.83	0	0.005	0.01	0.26	7	10	0.56	n.a.	n.a.
2	Three-step	Progresso	2013-02-17	6.69	n.a.	3.91	0	0	0	0.31	12	9.3	0.56	n.a.	n.a.
3	Three-step	Progresso	2013-02-17	6.67	n.a.	4.13	0.05	0.008	0.01	1.16	29	10.3	0.52	n.a.	n.a.

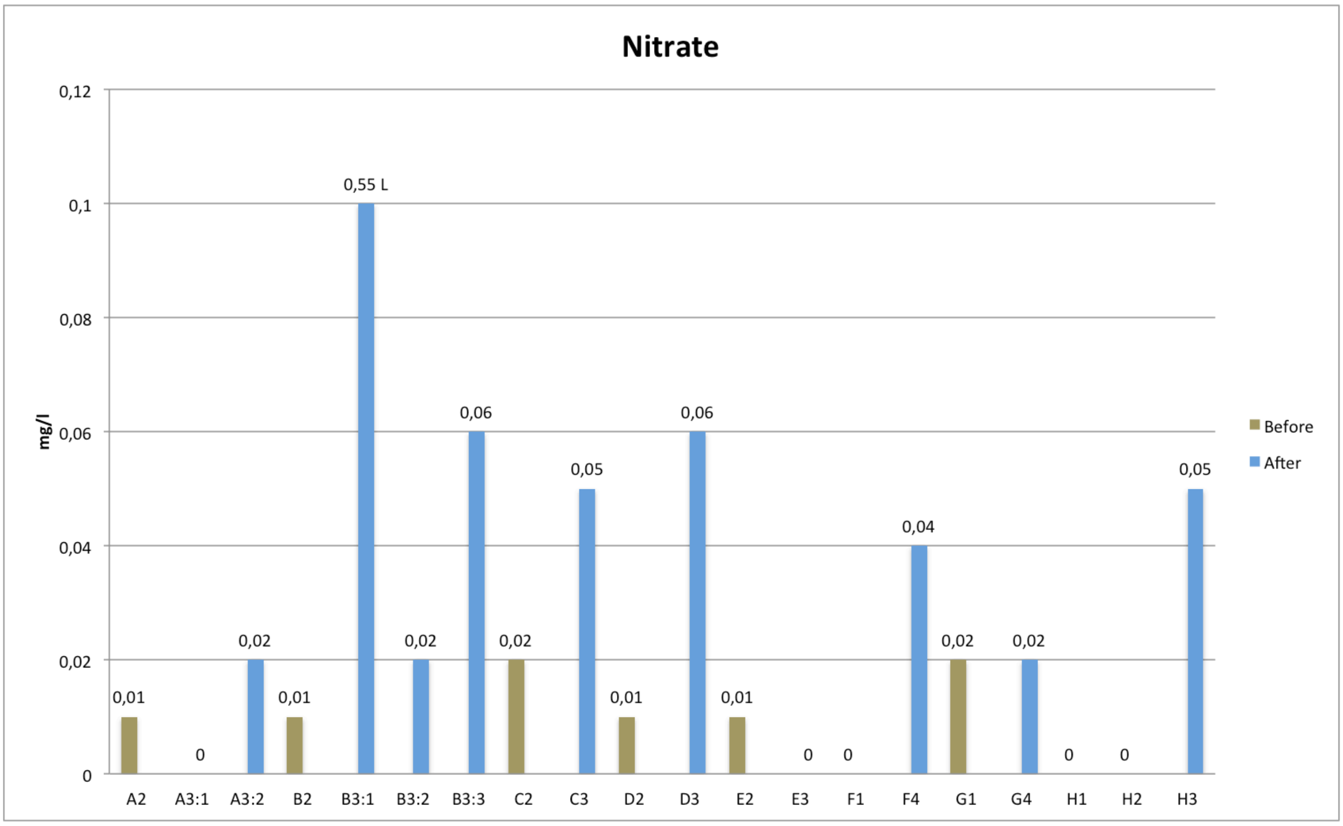
Appendix 6

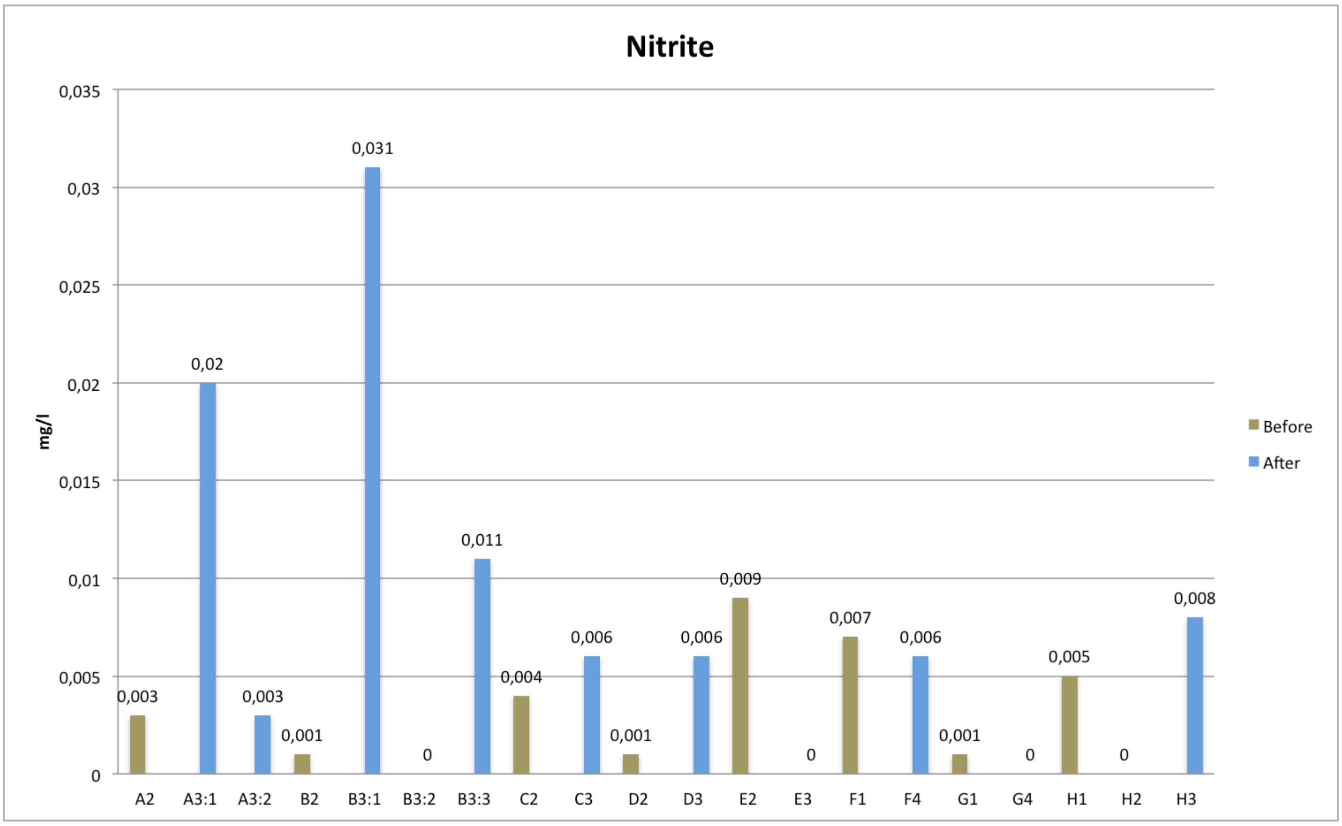
Diagrams of results






Oxygen
mg/l
8
7
6
5
4
3
2
1
0
3,86
3,69
3,83
5,25
2,5
3,8
5,55
3,55
3,86
6,05
6,76
6,64
6,62
3,53
4,5
2,44
4,37
4,83
3,91
4,13
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After


Nitrate
mg/l
0,12
0,1
0,08
0,06
0,04
0,02
0
0,01
0
0,02
0,01
0,55 L
0,02
0,06
0,02
0,05
0,01
0,06
0,01
0
0
0,04
0,02
0,02
0
0
0,05
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After


Nitrite
mg/l
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
0,003
0,02
0,003
0,001
0,031
0
0,011
0,004
0,006
0,001
0,006
0,009
0
0,007
0,006
0,001
0
0,005
0
0,008
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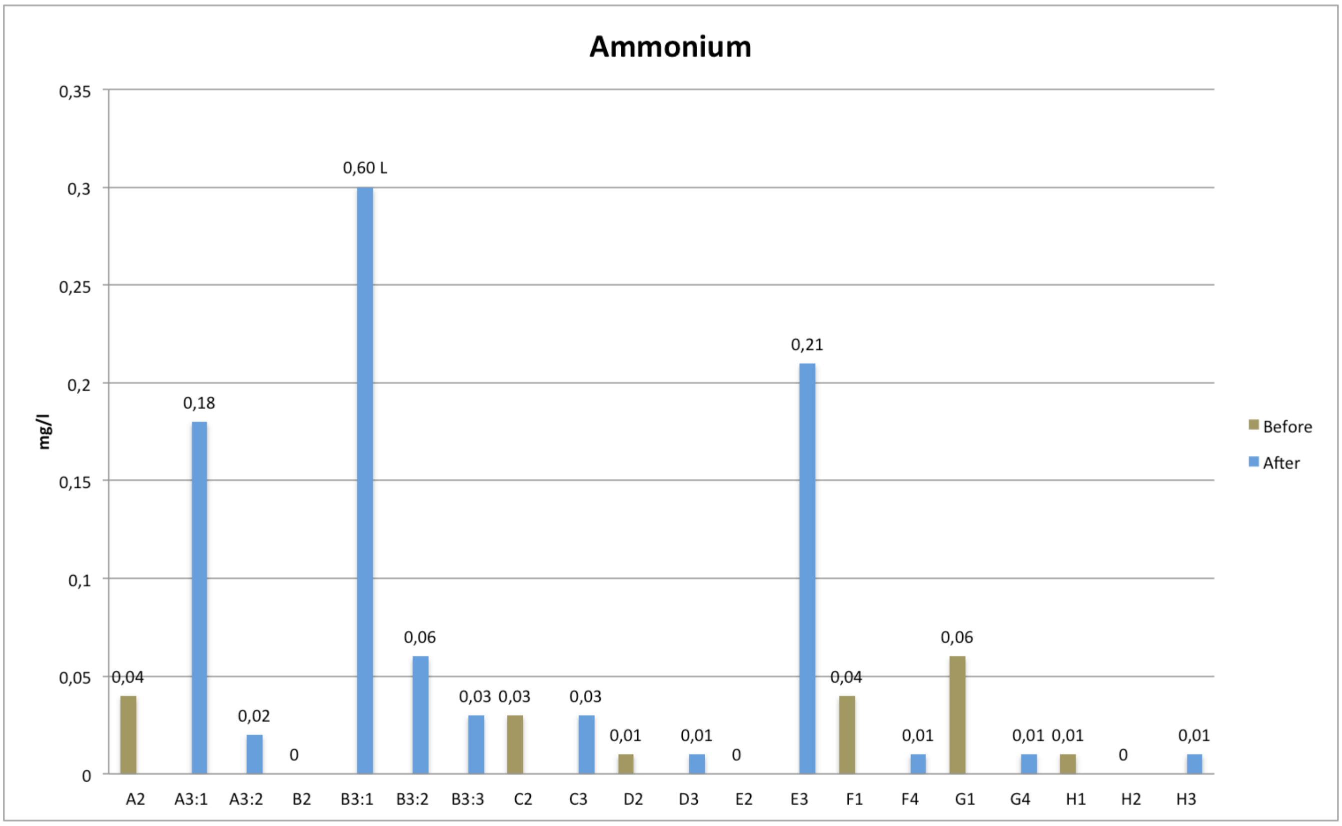
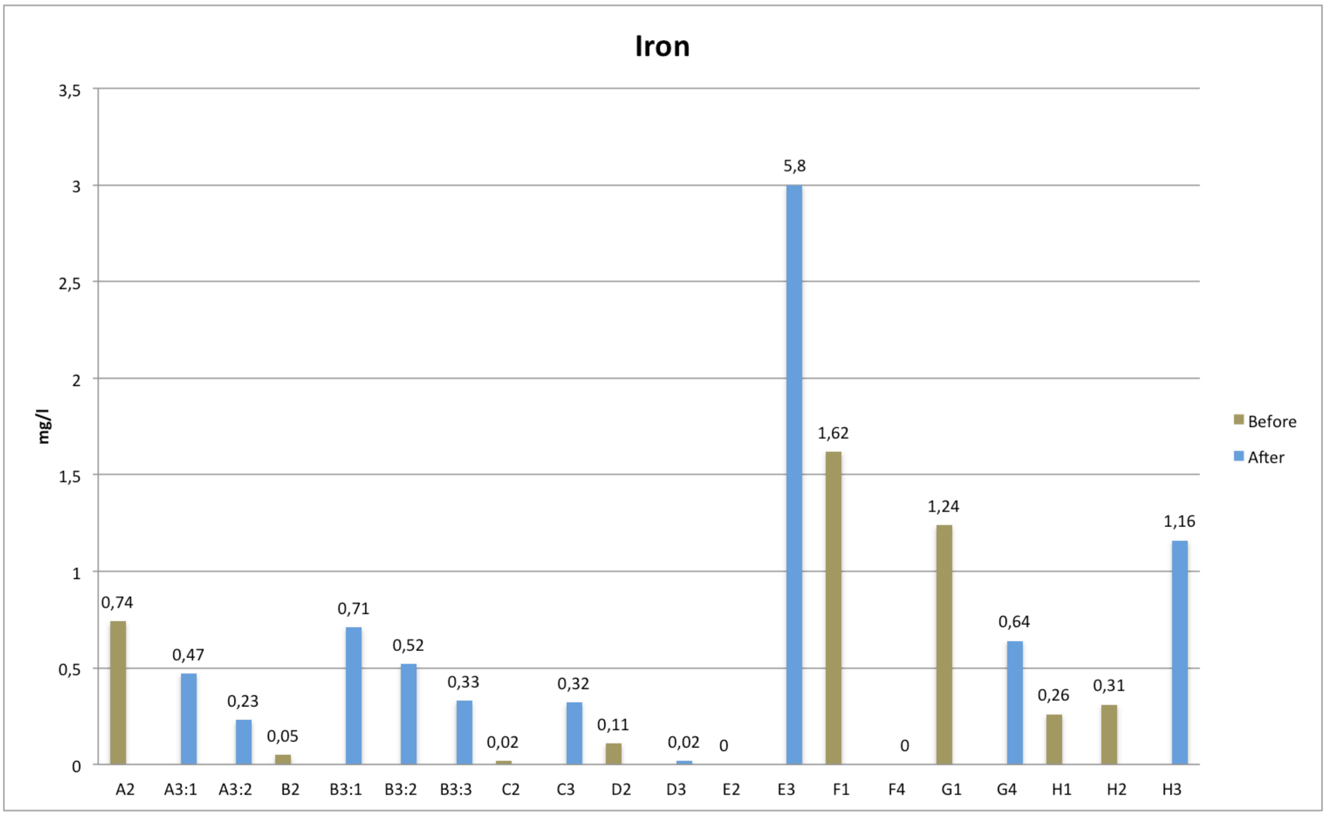
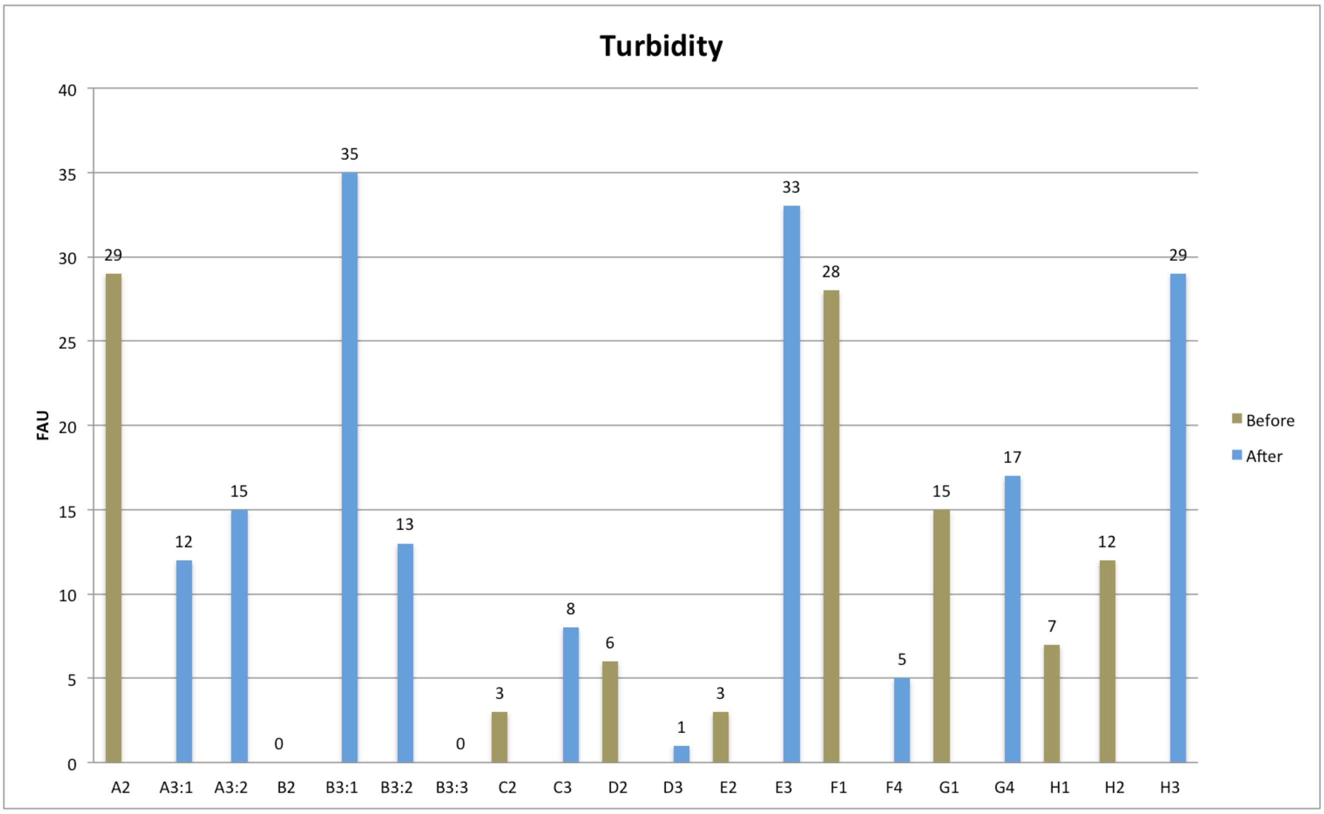
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After

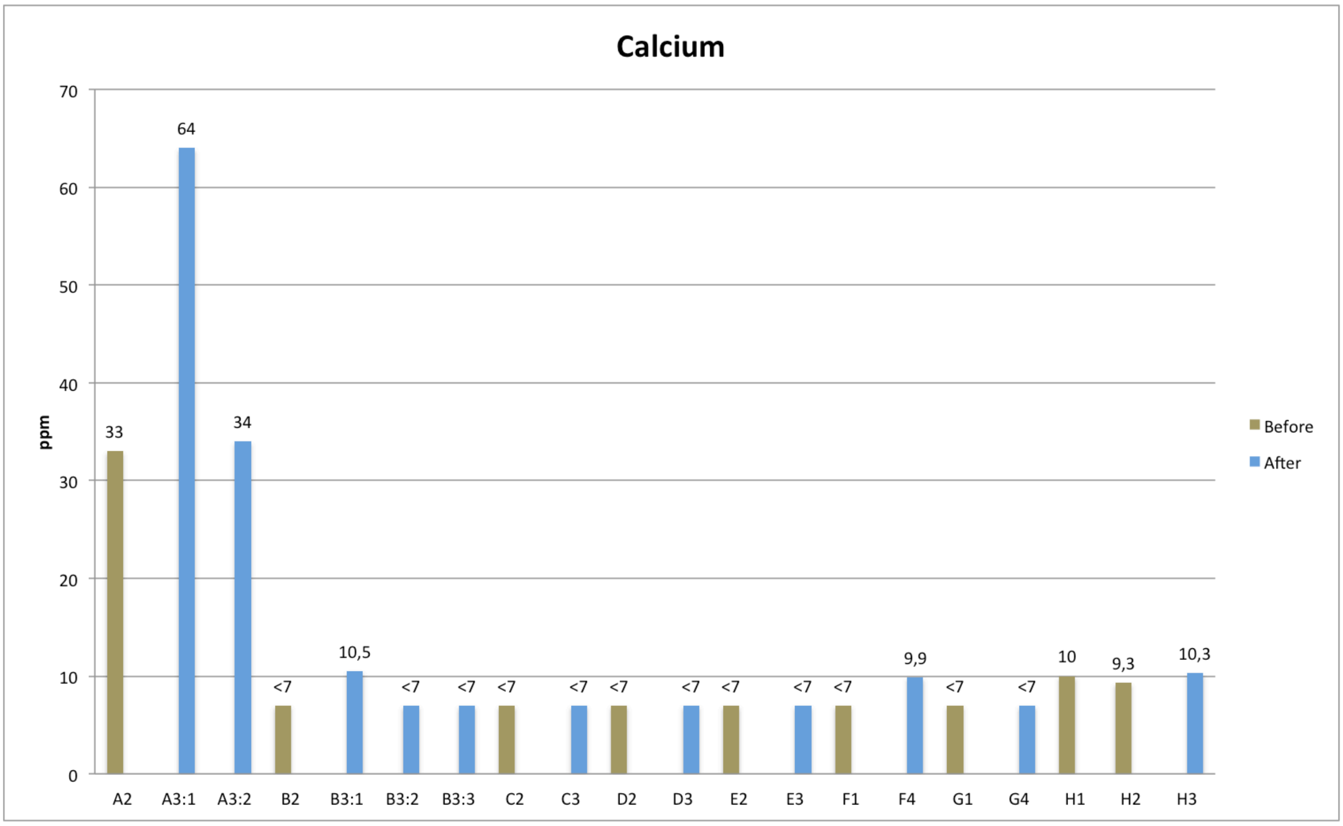

Ammonium
mg/l
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
0,04
0,18
0,02
0
0,60 L
0,06
0,03
0,03
0,03
0,01
0,01
0
0,21
0,04
0,01
0,06
0,01
0,01
0
0,01
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After

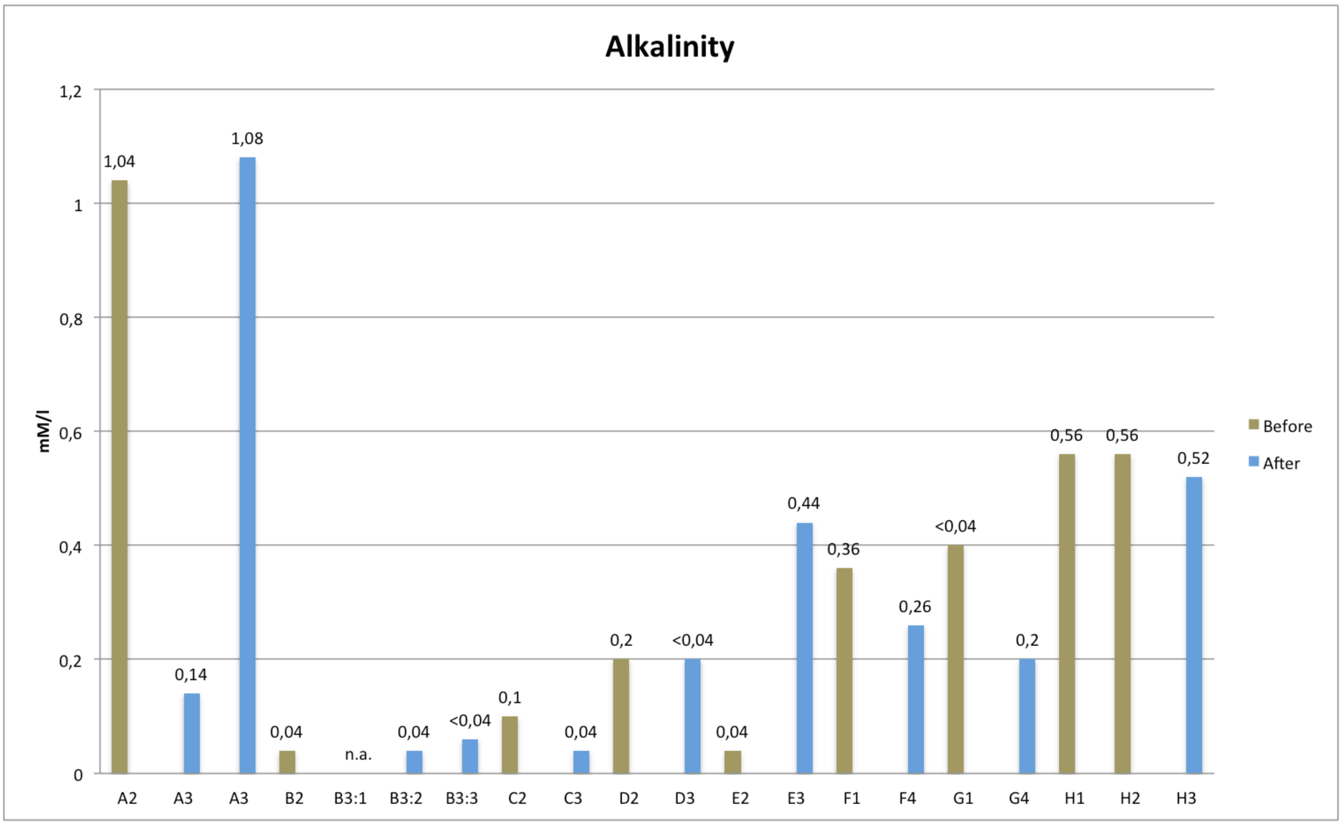


Iron
mg/l
3,5
3
2,5
2
1,5
1
0,5
0
0,74
0,47
0,23
0,05
0,71
0,52
0,33
0,02
0,32
0,11
0,02
0
5,8
1,62
0
1,24
0,64
0,26
0,31
1,16
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After



Turbidity
FAU
40
35
30
25
20
15
10
5
0
29
12
15
0
35
13
0
3
8
6
1
3
33
28
5
15
17
7
12
29
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After


Calcium
ppm
70
60
50
40
30
20
10
0
33
64
34
<7
10,5
<7
<7
<7
<7
<7
<7
<7
<7
<7
9,9
<7
<7
10
9,3
10,3
A2
A3:1
A3:2
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After


Alkalinity
mM/l
1,2
1
0,8
0,6
0,4
0,2
0
1,04
0,14
1,08
0,04
n.a.
0,04
<0,04
0,1
0,04
0,2
<0,04
0,04
0,44
0,36
0,26
<0,04
0,2
0,56
0,56
0,52
A2
A3
A3
B2
B3:1
B3:2
B3:3
C2
C3
D2
D3
E2
E3
F1
F4
G1
G4
H1
H2
H3
Before
After