CHALMERS

A Sustainable Laundry Solution
- With focus on water optimization in Cochabamba, Bolivia

Bachelor Thesis in Civil Engineering

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Cover: Women washing at a laundry place in Cochabamba.
Helgegren, I., 2014.

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Preface

This report has been written as a bachelor thesis for the division of Water and Environment Technology at Chalmers University of Technology in Gothenburg and it is a part of a continuous project in Cochabamba, Bolivia.

We have received a lot of advice, support and guidance during the work process of this report. Therefore we would like to thank the people that have shared their time and knowledge with us.

Thank you Peter Norberg; Senior Advisor Water Supply, Mattias Ivarsson; Building physics engineer, Roland Magnusson; Indoors climate expert and Stefan R. Andersson; Vice president for Building Services Engineering. All of them are from COWI and guided us towards asking the right questions and answered all of our mails with helpful ideas. Also, thanks to Malin Kempe; Energy Efficiency Engineer at CONSAT, who helped us to limit our questions. Mikael Mangold, Doctoral student at the division of Water Environment Technology at Chalmers University of Technology, has helped us with valuable insights.

Thank you Ida Helgegren, Doctoral student at the division of Water Environment Technology at Chalmers University of Technology and one of our supervisors, who has been in Cochabamba during the project and has been very helpful with essential on-site information.

And finally, thank you Sebastien Rauch, Associate Professor at Chalmers University of Technology, our supervisor who followed and helped us throughout the work process and kept discussing our goals and limitations.

Gothenburg, May 2014

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Sammanfattning

Att handtvätta kläder är en stor del av många människors vardag. Det kräver mycket tid och stor mängd vatten. Tillgången till rent vatten är begränsad i många utvecklingsländer, även om det räknas som en grundläggande rättighet. På grund av detta börjar gråvatten bli en viktig fråga i utveckling av ett hållbart samhälle, där återanvändning av vatten kan bli en avgörande tillgång. Eftersom att tvätt av kläder kräver mycket vatten, finns det potential att optimera användandet av de bristande vattenresurserna. Målet för detta projekt var att föreslå ett koncept för tvätt av kläder med användning av maskin i Cochabamba, Bolivia. Konceptet innefattar ett vatteneffektivt sätt att tvätta som är applicerbart ur ett ekonomiskt, socialt och ekologiskt hållbart perspektiv i ett område med bristande resurser.

Konceptet hoppas ge en lösning för hur man tvättar kläder i en maskin för att minska tidsåtgången för klädtvätt, men också spara färskvatten och minska utsläpp av kemikalier från tvättvattnet. Förhoppningsvis kan konceptet förbättra och ge en hållbar lösning till en annars krävande vardagssyssla.

Metoder som har används under arbetets gång har delvis varit litteraturstudie samt kontinuerlig kontakt med handledare på plats i Cochabamba, och svenska experter från industrin. Olika metoder för behandling av gråvatten jämförs sedan i en MCA-analys, där de betygsätts under kriterier berörande reningsgrad, social acceptans och krävda resurser, baserat på en potentiell implementering i Cochabamba.

En teknisk lösning för vattenrening presenteras som resultat från MCA-analysen, där ett långsamt sandfilter kopplat till en trekammarbrunn och ett fiberfilter är den rekommenderade idén. Denna lösning skulle behandla det utgående gråvattnet från tvättmaskinen och göra återanvändning tillbaks till tvättmaskinen möjlig. Det behandlade vattnet från systemet skulle även vara rent nog för bevattning och andra vardagssysslor.

Förslag till implementering av den tekniska lösningen, innefattande tvättmaskin och reningssystem, analyseras och två alternativ föreslås. Det första är en gemensam tvättstuga, där man tvättar själv för självkostnadspris. Tvättstugan kan förslagsvis implementeras i ett kooperativ eller i ett bostadsområde. Det andra är en affärsidé där man betalar för tvättservice, vilket skulle generera en inkomstkälla för minst en person i området. Beräkningar angående ekonomi i de båda förslagen presenteras.

Förhoppningen är att detta koncept skall kunna implementeras i Cochabamba, och möjligen på andra ställen med bristande vattentillgångar där det finns behov för en förbättrad tvättsituation.

Nyckelord: Tvätt, Handtvätt, Vatten, Cochabamba, Gråvatten, Återanvändning, Hållbart, Sandfilter, Vattenbehandling

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Summary

Doing laundry by hand is a part of everyday life for many people. It demands a substantial amount of time and water. Access to fresh water is limited in developing countries, even though it is a fundamental right. Therefore wastewater is becoming an important issue in sustainable development where recycling or reuse of the wastewater is emerging as a fundamental part of water usage. Reusing wastewater is considered a strategy for saving water and since laundry consumes a lot of water, there is a potential of optimizing the water usage. The aim for this project was to find and suggest a concept of doing laundry in a washing machine, in a water efficient way that is applicable from economic, social and environmental aspects in Cochabamba, Bolivia.

The concept is meant to give a solution to wash clothes in a machine, in order to minimize time occupation for laundry, but also save fresh water and decrease pollution from laundry wastewater. Hopefully, this concept can provide a sustainable solution to a demanding everyday task.

The methods used in the work process have been a study of literature, as well as an ongoing contact with supervisors on site in Cochabamba and Swedish experts from the industry. In this report different methods to treat grey water are explained and discussed. The treatment methods are compared in a MCA, where they are scored after different criteria concerning treatment efficiency, social acceptance and resources.

A technical solution is presented as a result of the MCA, where a slow sand filter connected to a three-step sedimentation system and a filter for collection of floating fibers is the recommended idea. This system would treat the outgoing wastewater from the washing machine, in order to make reuse of the water possible. The treated water from this system would be clean enough for reuse in the washing machine, but also for usage in irrigation and other everyday tasks.

The implementation of the technical solution in Cochabamba is analyzed and two financial solutions are suggested. One of them is the idea of a laundry business, which could generate a source of income for at least one person in the neighborhood. The second suggestion is a self-service laundry, where a cooperative or a neighborhood can utilize the washing facility. Economic calculations of both solutions are presented.

The hope is that this concept with a washing system can be implemented in Cochabamba and in other places where water resources are scarce where there is a need for an improved laundry situation.

Key words: Laundry, Washing by hand, Water, Cochabamba, Wastewater, Reuse, Sustainable, Sand filter, Water treatment

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1 Introduction

Washing clothes is an everyday task for people around the world and it is one of the activities in a household that requires a large amount of water. Laundry has an important part in our everyday life as it affects hygiene, economy and social functions. Since washing is mostly done with detergent and chemicals, it also concerns environmental aspects. The development of a sustainable and efficient laundry system can play a big role in households and also have a positive effect on the progress in developing societies.

The procedure of washing clothes varies from different countries; it depends on how the general living standards are in the area. According to professor Hans Rosling (2011) as many as 70 percent wash their clothes by hand. The invention of the washing machine has created an opportunity to ease the work of doing laundry and also gain time. The laundry machine is effective regarding how clean the garments become in relation to the amount of water being used.

Washing by hand is a time consuming and physically challenging task. In developing countries, the majority doing the laundry are women. In countries with water scarcity, about a third of household water is used for laundry by hand (Unilever, 2013). People in areas with lack of water can spend a significant part of their income on water and therefore the laundry can be costly (Ledo, 2007).

Access to fresh water is a fundamental human right and taken for granted in developed countries, despite that more than 760 million people get their freshwater from unsafe sources. Inadequate access to safe water and sanitation coupled with poor hygiene practices and sickens, leads to impoverishment and diminished opportunities for thousands more. (UNICEF, 2013) In major parts of the world, especially in countries with poverty, lack of water is a daily struggle (Unilever, 2013).

Bolivia is the country with the single most widespread poverty in South America (Svalorna, 2011) and Cochabamba is one of the most vulnerable areas in Bolivia regarding water resources. The city has a raining period of three months per year and has no usable surface water due to high pollution rates. Poverty in Cochabamba has in some areas kept the laundry method from developing and in most cases women do the washing by hand. In these areas the dirty laundry water is poured out in nature due to the lack of a functioning sewage system.[1]

This project aims to find a sustainable concept of doing laundry in the area Plan 700 in Cochabamba, Bolivia. A successful concept can possibly be used in other parts of the world where there is a similar lack of water. The focus is to develop the laundry concept with a washing machine and a system for reusing the grey

[1] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

water discarded from the washing machine. Further the concept is to be analyzed regarding economic, environmental and social aspects.

1.1 Problem description

The current situation for women in Bolivia usually involves washing by hand. The problem increases with the lack of fresh water, which is expensive and delivered in low volumes. This creates a situation where water needs to be reused for as many everyday tasks as possible. The idea of the project is to reuse the output water from the washing machine.

The concept will consist of a fairly complete washing system where parts such as water volumes, separation and filtering, housing requirements, energy consumption, waste water treatment, ownership and management needs to be examined with economical and efficiency aspects. The concept should generally improve the situation for women by reducing the time and physical demands of washing. This increases the possibility for women to gain employment or education and is a stepwise work towards a more equal and developed society. Introducing this technology to a less developed community will hopefully help the process of social improvement in these areas.

Another current problem in the studied area, Plan 700, is the lack of waste management. Grey water, such as the wastewater from laundry, is left in nature due to absence of drains. This, depending on the detergent used, can give various consequences for the local fauna. The concept described in the thesis will give an option of environment friendly waste management.

1.2 Limitations

An amount of limitations have been set during the work process, to give the project a manageable size and assumptions are made throughout the whole report in order to simplify necessary estimations.

In the concept a regular washing machine and ordinary washing powder that can be purchased in Cochabamba is used for the laundry. The washing machines internal technical systems will not be explained in detail, and calculations will not be made in terms of such specifics as pressures and sizes. The washing machine will be a standard type regarding water and energy consumption. These assumptions are made to make it feasible in terms of implementation and usage that will be applicable in different areas.

The time limitation did not allow evaluation of more than four water treatment methods. All of the compared water treatments methods are considered as feasible for this project. Furthermore, there are no thoroughly description of the theory behind MCA analyses, the payback method and the break-even chart.

Due to the time and financial limitations there was no possibility to travel to Cochabamba to evaluate the actual area of study. This makes it more difficult to obtain information about for example costs and social factors. Further, no laboratory experiments have been made on the water treatment system, which mainly depends on lack of time and resources. In Cochabamba electricity is available and possibilities to energy optimize has not been investigated, also due to time limitations.

1.3 Method

The project is partly a study of literature. The subject of review was water treatment methods combined with information about the grey water content. This resulted in a multi criteria analysis, MCA. For this criteria chosen with focus on the possibility of implementation result in a selection of the best suitable method for wastewater treatment in the studied area. The method was then further developed into a technical system, which will be feasible in Cochabamba.

Information and facts about the area Cochabamba, the life and people, have mainly been received from Ida Helgegren, a doctoral student from Chalmers University of Technology. She has been working in Cochabamba during the spring 2014. Continuous contact with her was conducted by email.

To implement the laundry system into the area, two solutions were developed; a business solution and a self-service solution, which both have been evaluated regarding economic aspects. A break-even chart has been made for the business solution to evaluate the profitability. To evaluate investment costs for the business solution, the payback method has been used. The working process for the entire concept is illustrated in figure 1.

During the work process there were meetings and interviews with representatives from the industry, a continuous contact with experts at COWI, and an energy expert at CONSAT. This gave further understanding about existing solutions and the possible applications of the ideas.

Chalmers University of Technology hosted a workshop together with HSB and NASA in the beginning of February, on the theme “Rethinking laundry on earth and in space”. The majority of the group participated and the thought process about laundry and washing started. The group gained inspiration and knowledge from experts in the field about innovative laundry systems.

In the summer of 2014 a Chalmers master's student is going to Cochabamba with the intent to implement the laundry concept. This is an opportunity to evaluate if the purpose is achieved.

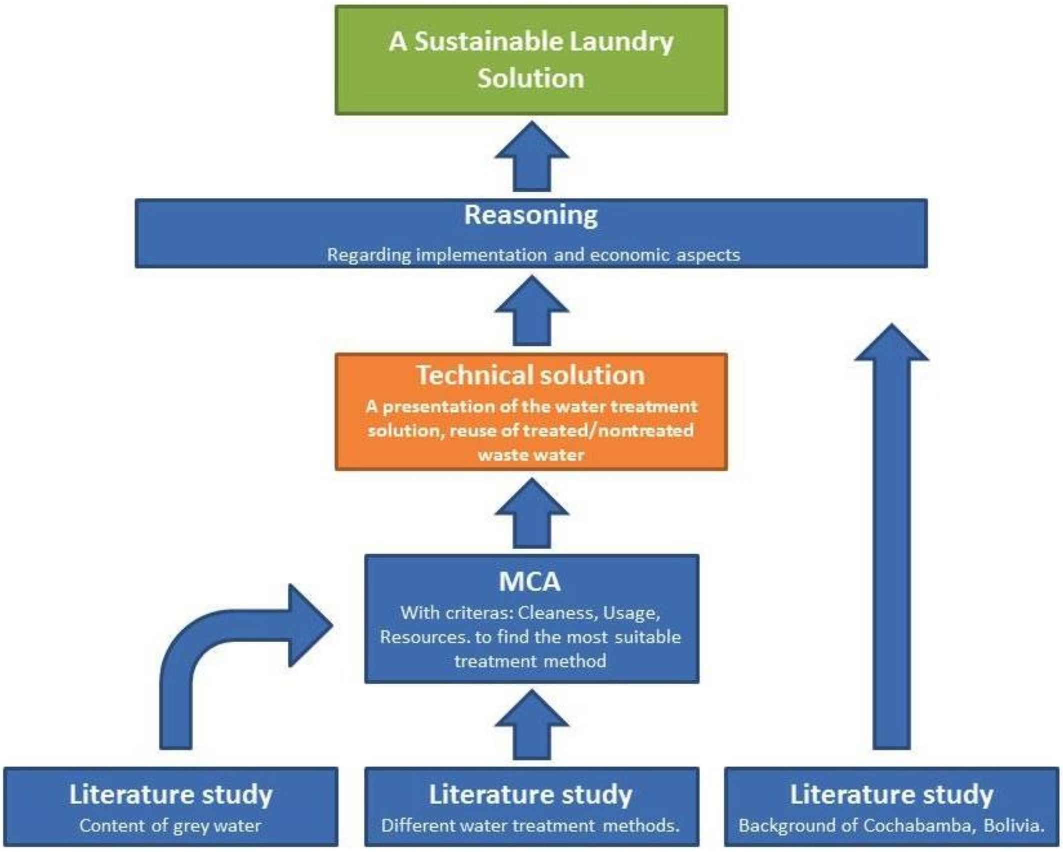

Figure 1: A schematic illustration of the work process.

2 Cochabamba

Cochabamba is one of the departments in Bolivia with a city that is also called Cochabamba. It is located in central Bolivia, see figure 2, in a valley in the Andes mountain region (Adelantebolivia). Cochabamba city is the third largest in the country and is estimated to have 800 000 inhabitants. The department of Cochabamba, which includes both metropolitan and suburban areas, has 1 600 000 inhabitants. (Landguiden, 2012)

Figure 2: Map over South America with Bolivia and the location of Cochabamba (projects-abroad).

2.1 Climate

The climate in Cochabamba is mild with warm days and cold nights and it is considered the best in Bolivia (Boliviaweb, 2012). The hot season, which is considered from October to April, has the average temperature of 26 degrees (World Weather Online, 2013). There is a rain period during the summer months, which is from about January to March and have an average rainfall of 55 to 96 mm per months (World Weather Online, 2013). The climate is suitable for agriculture and Cochabamba is one of the major agricultural areas in Bolivia (Sustainable Bolivia).

Bolivia's location between the Andes and Amazonas makes it vulnerable for climate change. As the rain period gets shorter and the average heat gets higher, farmers face difficulties providing for themselves. The fact that Bolivia is a poor country makes it even more vulnerable to the consequences of climate change. (Sida, 2011)

2.2 Economy

As one of the poorest countries in South America, Bolivia struggles with almost half of the population living in poverty or extreme poverty (UNICEF, 2013). While some areas in the country remain rural and poor others are undergoing development and urbanization. The metropolitan region of Cochabamba has a rapid population growth and also an economic progress due to urbanization. This area consists of wealthy as well as poor parts and it has a rapid development and changing rate (Peltovouri, 2004). Regardless of the fast progress rate in some areas, Cochabamba city still has poverty and the metropolitan area has an extreme poverty rate that is just below 30 percent (UDAPE-UNDP, 2010). As urbanization cause an increasing development it also has its disadvantages such as that the infrastructure does not keep up with the rapid development which in turn leads to informal establishments lacking proper water and sanitation facilities. The rapid growth of Cochabamba has resulted in settlements in areas better suited for agriculture, which leads to many people, already poor, losing their possibility to an income. (Fohlin and Johansson, 2001)

The poorest parts in the south of the department of Cochabamba struggle with the most basic needs like water and sanitation and some of the areas have an extreme poverty rate at 69 percent (UDAPE-UNDP, 2010). Most vulnerable to poverty are the women and children (UNICEF, 2013). Ida Helgegren, a doctoral student at Chalmers University of Technology who works in Cochabamba, estimates that the total monthly income for an average family in Cochabamba is approximately between 1 000 and 4 000 Bolivianos, Bs, about 140-570 US Dollars, USD. According to Instituto Nacional de Estadistica in Bolivia, the national minimum income was 1 000 Bs per month in 2012 (Instituto Nacional de Estadistica, 2014).

2.3 Plan 700

The area in focus of the project is an informal community, called Plan 700, located on a hillside in the southern part of the city of Cochabamba, as seen in figure 3. It consists of pastureland and mostly of porous and instable material, which is a problem during the rain period when it erodes. (Nilsson and Olsson, 2013)

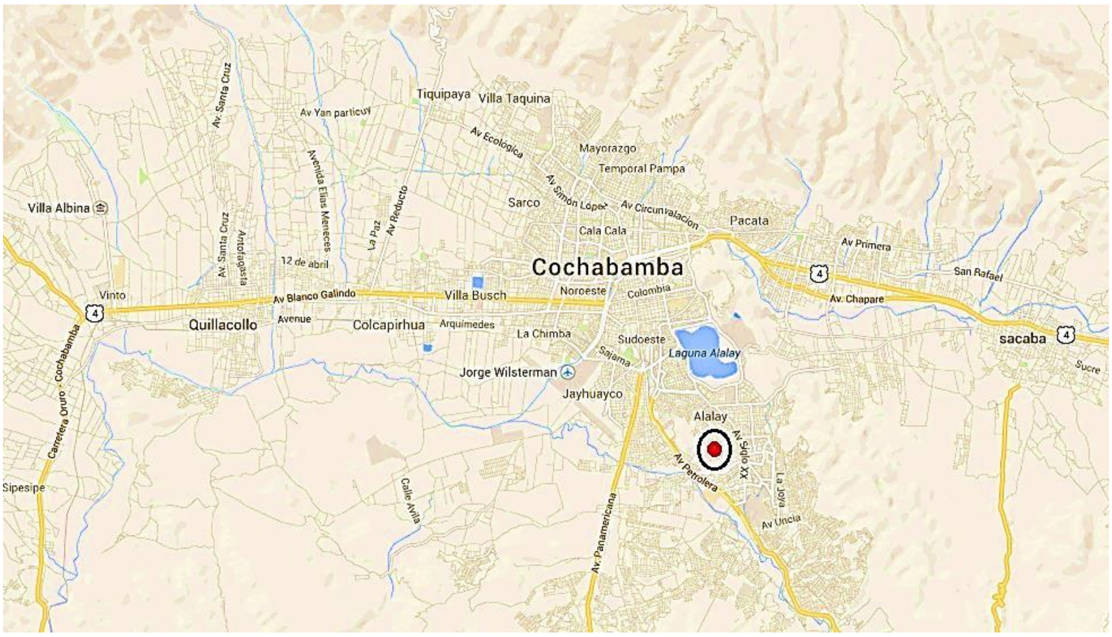

Figure 3: Map over the city Cochabamba where Plan 700 is marked with a red point. (Google.es/maps, 2014)

Plan 700 is an area with large poverty and over 75 percent of the households do not live up to the minimum living standard criteria, according to The Universal Declaration of Human Rights by the United Nations. This mostly depends on the facts of living in crowded conditions and the deficiency of basic standards as sanitation and water supply. The number of inhabitants are 1 600 people in approximately 340 households, which is divided into 15 smaller neighborhoods, which can be seen at figure 4 were each letter represent a neighborhood. The majority is native migrants, who has settled in Plan 700 because of satisfying climate, lack of job in the countryside, being single women or just because the land is available here and families can build their own house instead of renting. (Nilsson and Olsson, 2013) It is an area with high cultural diversity with different ethnic origin, different education levels and several languages.[2]

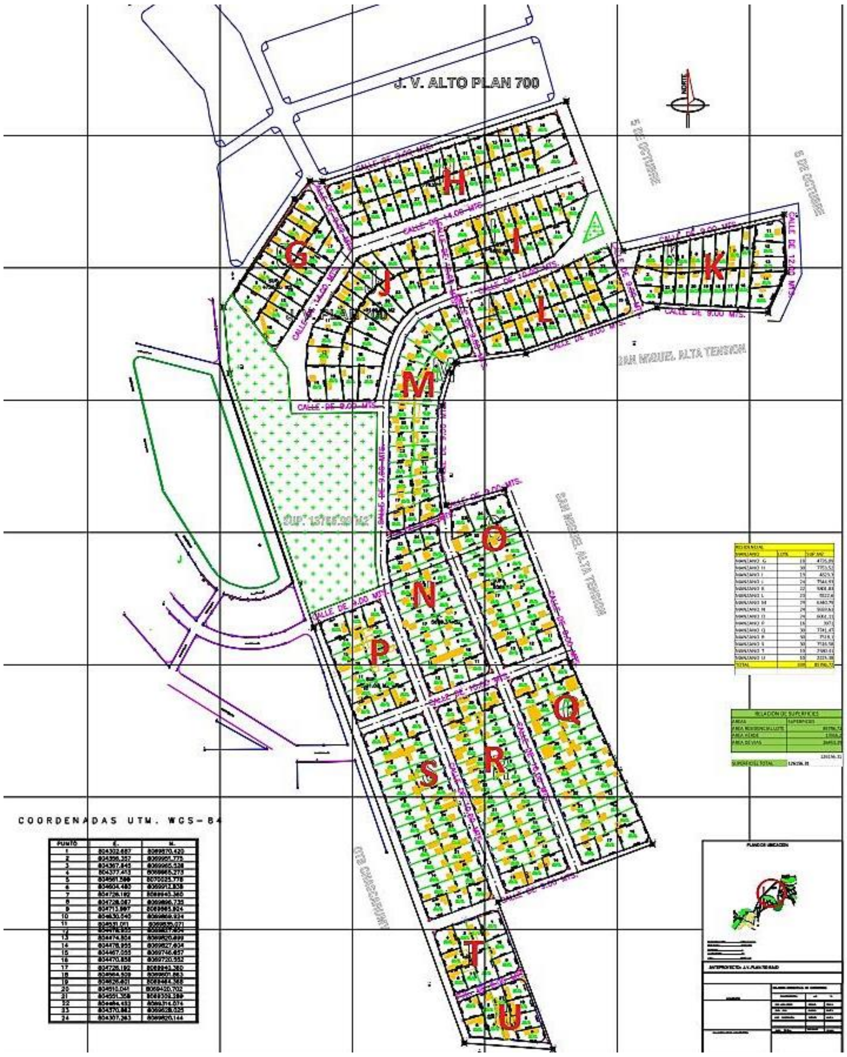

Figure 4: A map over Plan 700, were each letter represent a neighborhood. The neighborhood Q does not exist in Plan 700 anymore. (Procasha, 2014)

[2] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

Generally the men are working while the women often are at home, taking care of the household and children. Single or widowed women are often depending on assistance from their children. The work is dominant in the informal sector that includes transport, trade and construction and the income is often immediate, not a monthly salary. (Nilsson and Olsson, 2013)

The access to electricity is good in the area, all households has a possibility to use it. However the area lacks the access to piped water and drainage system and the infrastructure of the area is deficient much due to the crowded conditions. (Nilsson and Olsson, 2013)

In the area there is a community-based organization called "Junta Vecinal". This minor organization consists of representatives from each neighborhood. They work as a member's board for the community to improve the area in different ways such as development in water questions and improving infrastructure.[3]

2.4 Cooperatives in Cochabamba

A cooperative is an association of people that voluntarily meet because it benefits them in their common economic, social and cultural needs (ICA, 2014). The cooperative can take many forms but has the principle of each member's democratic and economic influence. The cooperatives often also have a strong connection and therefore a concern for the local community as it consists often mostly of local members (Division for Social Policy and Development, 2014)

In the area of Cochabamba it is common with cooperatives; examples are housing cooperatives or working cooperatives. PROCASHA is a foundation working in the area that helps to construct these cooperatives. The definition of cooperative that PROCASHA use and the International Co-operative Alliance set is: "A cooperative is an independent association in which the people voluntarily organize themselves to satisfy their economic, social and cultural needs through funding an organization that they put together and run democratically" (International Co-operative Alliance, 1995), (Procasha, 2014).

PROCASHA has six working-cooperatives in the Cochabamba area where one of these is a working-cooperative in the Plan 700 area. The cooperative in Plan 700 consists of about ten women, which are living in different neighborhoods. They are learning to build and improve their own houses. With the help of PROCASHA they are able take loans, borrows tool and receive building knowledge. With this experience they are able to work and help others with construction.[4]

[3] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).
[4] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

3 Water

According to FN, access to pure water is a human right and this was established in 2010 after 15 years of discussion (TT, 2010). The access to fresh water is unevenly distributed over the world and over one billion people do not have access to pure water. Mainly people in countries with poverty lack this access and water is a major problem and a daily struggle. (UNICEF, 2013) The lack of water is decreasing living standards by affecting factors as the health, hygiene and daily life. 80 percent of diseases in the developing countries are related to poor water quality and bad hygienic conditions. There are 3.4 million deaths every year related to water illnesses, from which diarrhea is the most common mortal disease. (UNICEF, 2013)

The definition of water access, according to The World Bank, includes piped water or improved drinking water sources like public taps, tube wells, protected springs or rainwater collections. The water quality in Bolivia differs a lot and the supply can be uncertain. In the countryside the water supply systems with pipelines and water on tap are underdeveloped. In cities many pipelines are leaking, which result in big amounts of water not reaching the taps, due to bad infrastructure. (Garat, 2013)

3.1 Water in Cochabamba

There is a system of piped water in Cochabamba, but it does not cover all areas. In 2001, around 50 percent had access to the water network. (Ledo, 7) The water quality is poor and the cost for the water is varying due to location and wealth of the household (Vargas, 2011). The ones who are connected to the water supply network have various quantity of water due to that the systems have different capacity (Peltovouri, 2004). About 50 percent of the water is estimated to get lost in leaks and illegal connections of water pipes (Vargas, 2011). In the richest households in Cochabamba, there is an average use of 165 liters per person per day and the water cost is generally less than one per cent of the family income. The poorest people, usually living in the outskirts, use an average of 20 liters per person per day, which cost them around 10 percent of their already low income. (Ledo, 2007)

3.1.1 Truck water delivery

Water delivered by truck is the most common access to water in areas that are not included in the water network. Plan 700 is one of the areas without piped water that uses truck delivery[5]. This costs about five to ten times more than the piped water (Vargas, 2011). In figure 5, the areas in Cochabamba, which people get their water delivered by truck are showed. The water system in the south of Cochabamba consists mainly of water truck delivery and is the only option since the houses are built on hills (Ledo, 2007), this water costs, for example in Plan 700, about five bolivianos for 200 liters. The lack and expense of water make

[5] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

people reuse their water in as many ways as possible.[6] This can lead to consequences, as improper reuse of water can decrease health situations and even cause death where children are most vulnerable. (UNICEF, 2003)

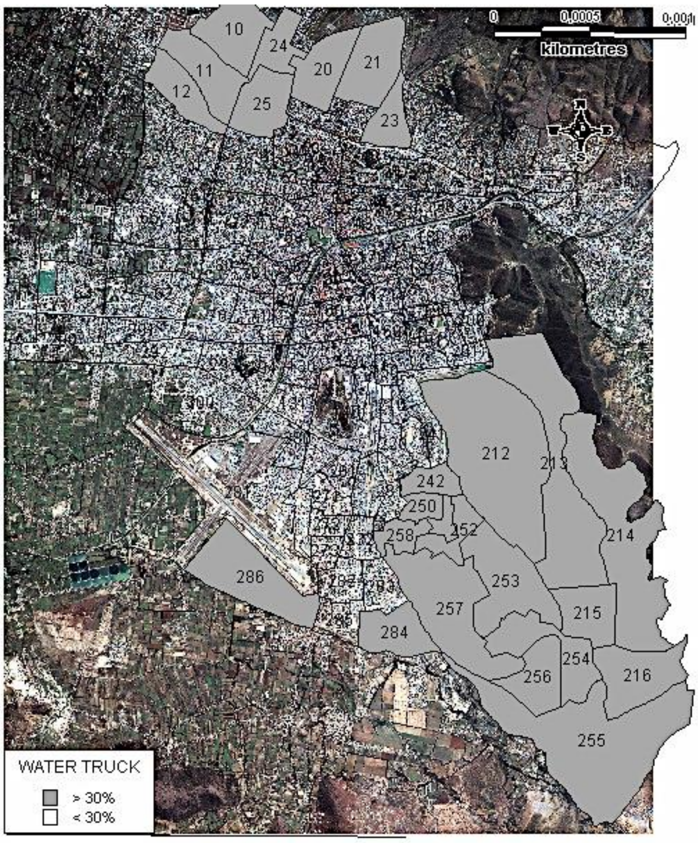

Figure 5: Map over Cochabamba and the areas of which people get their water delivered by truck, marked with grey. (Ledo, 2007)

3.2 Water Usage

Water bought from trucks is stored in oil drums or big plastic barrels. The water is used for all everyday tasks demanding water such as showering, cleaning and cooking. Washing dishes and doing laundry are both mainly done in cold water; otherwise the water is heated on the kitchen-range. A small part of the water is used for household cleaning but this and all the other household tasks differ in water consumption between families and their respective income. Doctoral student Ida Helgegren, estimates that a family with three children usually buys around 800 liters of water per week. The water is used sparingly and reuse is made as much as possible; as an example the water people use to wash themselves with in the morning is later used to water the flowers.[7]

[6] Ida Helgegren, (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

[7] Ida Helgegren (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

3.3 The Water War in Cochabamba

After many years of economic instability in Bolivia, the government made several reforms after contact with the World Bank. This included privatizations of public services, and the water distribution in Cochabamba was one of the topics. The municipal water supply SEMAPA, Servivio Municipal de Aqua Potable, was up for sale in 1999 and the only bidder was the private company, Aquas del Tunari. In September that year, Aquas del Tunari got contracts to provide water and sanitation services in Cochabamba for 40 years. The Bolivian government also established a law, 2029, which contained new restrictions about water supplies. The law made every private or cooperative water supply system illegal, which resulted in a monopoly of the drinking water system for Aquas del Tunari. (Nylander and Gad, 2008)

After Aquas del Tunaris takeover, the water prices increased highly. According to Aquas del Tunari the prices increased with only 35 percent but according to the government the increased was about 200 percent. The price increase was meant to finance a project called the Miscuni project, which concerned development of a water supply system to bring water to Cochabamba from the Miscuni River. (Lobina, 2000)

The people reacted strongly at the price increase and a new popular movement called La Coordinadora was formed. Civilian people from different parts of Cochabamba gathered and protested. The protests increased leading to demonstrations and road blocks that stopped all traffic to Cochabamba for four days. La Coordinadora arranged an unofficial referendum with fifty thousand participants where 96 percent were against the water privatization. The government did not react to the actions, which resulted in escalated protests. The culmination was when a 17-year old boy was shot dead by a Bolivian soldier in April 2000. Totally six people were killed, several people were injured and a lot of people were arrested. The government started to realize the situation and accepted the demand of La Coordinadora, so Aquas del Tunaris contracts were broken. SEMAPA was again the operator of water supply in Cochabamba. (Nylander and Gad, 2008)

4 Washing

Washing technique is important both from a health and hygiene perspective but also in social aspects. In countries with water scarcity, washing clothes is one of the everyday tasks in households that uses most water and therefore costs relatively much money for the users (Unilever, 2013). People in less developed countries usually do not have access to washing machines and therefore washes their clothes by hand. Hans Rosling (2011), professor of international health, estimates that there are two billion people with access to washing machines. This makes five billion people, a majority of the world's population, doing laundry by hand. Whether washing clothes is made by hand or by machine, the wastewater has a negative impact on the environment because of the content of detergent.

4.1 Washing machines

In the end of the 18th century a washing machine with a rotating drum similar to the one we use today was invented, with the difference that it was driven by manpower. After the Second World War washing machines spread for public use and this time it was driven by electricity. From the year 1950 to 1965 the percentage of apartment blocks with available washing machine increased from 8 percent to 90 percent in Sweden and today most of the people in developed countries take washing machines for granted. (Tekniska Muséet, 2012) The invention of the washing machine created opportunity for especially women to have more free time since hand washing demands much more time and the women has been responsible for the laundry through the history. Washing machines require, in addition to water, energy and the amount of energy needed depends on for instance water temperature and the machine used. (Göteborg Energi)

4.1.1 Different machines

Contemporary washing machines are programmable and automatic and except from loading laundry the machine manages the whole washing process itself. Research is being done on how to develop machines consuming as little water and energy as possible.[8] Further, systems such as showers which reuses most of the water has already been developed (Orbital Systems, 2014). The water and energy consumption differs much due to that type of machine is being used and how well loaded it is. There are two major types of washing machines; top-loaded and front-loaded. In Europe the most common is front-loaded which differs to other parts of world, as South America where top-loaded machines are more common. Compared with a top-loaded machine, the front-loading machine saves 40-75 percent water and 30-85 percent energy. A front-loaded machine is better for the clothes since it tumbles the clothes unlike the top loaded that jerks the clothes with a stirrer. The absence of the stirrer in the front-loaded also makes it easier to wash bigger items, for example carpets and sleeping bags. A front-loaded machine makes the drying time shorter since it removes more water from the clothes. (Bluejay, 2013)

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[8] Hackathon workshop conducted by the group in 2014-03-04 with representatives from HSB housing in Sweden and NASA, Houston, TX

The capacity of a washing machine varies but most machines manage six to eight kg laundries per cycle (Electrolux). In average, a washing cycle uses 50-67 liters of water. In Sweden it is optionable to use hot water in the washing machine and use different temperatures depending on the items. For a washing cycle of 60 degrees, the power use is 0.95-1.2 kWh. With 40 degrees, the power use is 0.6 kWh. (Göteborg Energi) The reason to wash in hot water is to eliminate bacteria, which require a water temperature of at least 60 degrees; the higher temperature will also help in the dissolution of fat. (Gustafsson, 2009)

The price for a washing machine differs depending on for instance technical solutions, capacity, manufacture, place and the occasional supply and demand. A certain shop in Cochabamba has prices between 200 and 500 USD[9], which is around 1 400-3 500 Bs. At websites selling washing machines in Cochabamba the prices vary between 2 400 and 4 000 Bs. A compilation of prices for several washing machines at the market is presented in appendix 1.

4.2 Washing in Cochabamba

In Bolivia, around 20 percent of the households do their laundry using a washing machine and 80 percent wash by hand (Euromonitor International, 2013). In recent years the middle class has acquired washing machines but hand washing is still the dominating method of cleaning. The laundry is done in washtubs or bowls filled with cold water or in streams and there also exist public laundry places, a picture of one of these is shown in figure 6. The most common detergent used is washing powder. After the washing process the wastewater are released in nature if no other option is available.[10]

[9] Ida Helgegren (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

[10] Ida Helgegren (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

Figure 6: A laundry place in Cochabamba. (Ida Helgegren, 2014)

Ida Helgegren, doctoral student at Chalmers University, has tried hand washing on site in Cochabamba. The water needed to clean 23 mixed items was about 90 liters and the use of detergent was 200 g. For one person the washing took 45 minutes. It is most common for people to do their own laundry but there are laundry services where one can pay for getting clothes cleaned in washing machines and the cost is about 15 bolivianos per kg laundry.[11]

4.3 Cost comparison washing by hand versus washing machine

The two washing methods of doing laundry, washing by machine and washing by hand, are compared to each other in the aspect of economy.

To find reasonable values of the cost of laundry, some assumptions are made, which also are used further on in the report. A front-loaded washing machine is used, since it uses less water and energy (Bluejay, 2013). By a comparison between washing machines on the market made in appendix 1, mean values have been calculated. The result shows a capacity of eight kg laundry, a water consumption of 56 liters per loaded machine and the price for the machine is set to 3 800 Bolivianos. One washing machine manages to do about 5 100 cycles during its lifespan (Yalanovsky, 2014), which is assumed as a reasonable value since several sources and a rough calculation gives similar results. The rent for needed land is set to 2 000 Bs per year.

Washing 23 items by hand uses 90 liters water and 200 g detergent, as in the test by Ida Helgegren in chapter 4.2. The amount of detergent used in washing machine is 100 g (Hygienshoppen, 2014). The cost for 900 g washing powder is 15 Bs in Cochabamba and the cost for 200 liters of water is five Bolivianos.[12]

4.3.1 Results of Cost Comparison

Results from calculations are presented below. The calculations are further presented in appendix 1.

The cost for washing laundry by hand is about one Boliviano per kg laundry, see table 1.

Table 1: The table shows the total cost for washing 1 kg laundry by hand. Calculations found in appendix 1.

Cost for hand washing 1 kg laundry	
Water cost	0.37 Bs/kg
Detergent cost	0.60 Bs/kg
Sum:	**0.97 Bs/kg**

[11] Ida Helgegren (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).
[12] Ida Helgegren (Doctoral student at the division of Water Environment Technology, Chalmers University of Technology).

The cost for washing laundry in machine is about 0.6 Bs per kg laundry, see table 2, which compared with one Boliviano for hand washing gives a cost reduction of almost half price.

Table 2: Shows the total cost for washing 1 kg laundry in machine.

Cost for machine washing 1 kg laundry	
Electricity cost:	0.10 Bs
Water cost:	0.18 Bs
Detergent cost:	0.21 Bs
Machine cost:	0.09 Bs
Sum:	**0.58 Bs**

4.4 Content of grey water from laundry

Grey water from laundry contents substances from humans such as dirt, human tissue, chemicals from the used detergent and also pathogens which is infectious agents. Laundry detergent contains different ingredients, which each has different purposes. The formulas are complex and are reflecting the diverse demands of the consumer market. Laundry detergents contain *builders*, *surfactants*, *bleach*, *enzymes* and many other agents. A regular detergent in Cochabamba is showed in figure 7 below. The content in grey water is strongly affected by the temperature of the cleaning water. (Forbrugerkemi 2011)

Figure 7: Picture of a common detergent that sells in Cochabamba and the content. (Sebastien Rauch, 2014)

4.4.1 Builders

Builders are water softeners, witch remove calcium, magnesium and certain other metal cat ions in hard water, resulting in a more soft water. This water is well matched with soap and therefore extends the lifetime of the plumbing. The problem with hard water is that the ions interfere with the action of soaps and help to build up the hard off-white chalky deposit called lime scale, which can foul plumbing and promote galvanic corrosion. (Forbrugerkemi, 2011) The most important are sodium carbonate and sodium tri-polyphosphate. Phosphate is high performing stimulant for algae, bacteria and fauna in rivers; lakes and oceans, making them bloom at very rapid rates. This means a comprehensive decay of the oxygen supply both at the surface and in the bottom layers of water bodies and therefore killing fish. (Yangxin et al, 2008) Comparison between powder- and liquid detergents shows that powders have a higher range of phosphorus concentration than liquids (Patterson, 2004). Sodium is one of many salts used in laundry detergent and has a serious effect upon reducing soil permeability as well as being toxic to plants. (Yangxin et al, 2008) Sodium sulfate is also used as filler taking no part in the washing action; this gives an excess amount of sodium and sulfate ions in the water. (Patterson, 2004)

4.4.2 Surfactants

Surfactants are usually organic compounds that lower the surface tension between two liquids or between a liquid and a solid. The mechanisms involve the adsorption of surfactants at the oil-solution and laundry interface, and remove the oil droplet from the laundry. Surfactants consist of both a hydrophobic group and a hydrophilic group, and according to the hydrophilic head can be classified into four groups: anionic, nonionic, cationic and zwitterions. Laundry detergents often contain a mixture of these different types of surfactants to strengthen their cleaning performance capability. At high surfactant concentrations micelles can occur, which is when surfactant aggregate, this is more commonly accepted in manual hand wash where surfactant concentrations can be very high. It is the formation of micelles in solution that gives surfactants their cleaning ability and solubility properties. (Laurent et al, 2007) Not all surfactant decomposes, as one would wish, some surfactant builds complexes, which are difficult to decompose in the nature. Others are toxic for aquatic organisms, while others have hormone-like effects. (Yangxin et al, 2008) Anionic surfactants, especially LAS; linear alkyl benzene sulfates, which are used in a greater volume than any other groups due to their ease and low cost of manufacture. (Laurent et al. 2007) LAS are one of these surfactants that only decompose under aerobic conditions and the problem is when anaerobic conditions exist as in the sediment of the surface water (Europeiska Gemenskapernas Kommission, 2009).

4.4.3 Bleach

Bleach consists of a number of chemicals that is added to remove color, whiten or disinfect by oxidation. Bleaching agents bleach stains that are not removed by the laundering process. Sodium hypochlorite and hydrogen peroxide are commonly used as bleaches. (Britannica, 2014) Sodium hypochlorite produces reactants, which decompose slowly in the nature. Sodium hypochlorite is very harmful to human health due to the etching effect can cause skin damage, and it is very toxic to aquatic organisms. However the compound is highly active and will react with the organic substances in the wastewater in the sewer before it reaches the wastewater treatment plants, but the question is what happens when people do not have access to proper plumbing. If the first organic compound available is human tissue during hand wash there could be a risk of a damaging reaction. (Eco-forum, 2013)

4.4.4 Enzymes

Difficult stains can also be removed with enzymes, which act on materials with stains as catalysts to speed up the chemical reactions so these materials can be washed away more easily with surfactants. Enzymes are proteins so they are completely biodegradable, non-toxic to plants and animals in the environment.

However enzymes can cause allergy if they are breathed in at very high concentrations or over a long periods of time. (Forbrugerkemi, 2011)

4.4.5 Evaluating of washing water

One-way to evaluate the potential environmental risks by using these chemicals are to get information about chemicals biodegradability. Biodegradation is an important factor indicating the fate of the components after their disposal into the environment; it is a process by which organic chemicals are broken down into smaller chemical units by living organisms. (Laurent et al, 2007) Two analytical techniques are used to measure the biodegradability and are measured under both anaerobic and aerobic conditions. Biological oxygen demand, BOD, measure the oxygen consumption of microorganisms in the oxidation of organic matter, and normally runs for five days and therefore gets the proper term BOD_5. Chemical oxygen demand, COD, measure the amount of chemical oxidant required to oxidize the organic matter. The relation between BOD and COD shows the biological degradability of the chemicals. (Kadlec and Wallace, 2009) Values show that laundry fraction contains 725-1815 mg/l COD and 48-472 mg/l BOD. (Erikson et al, 2001)

The wastewater should not be stored for more than 24 hours before use; this is because the Biological Oxygen demand, BOD, would increase with time. This is, in turn, due to the bacterial activity on the water contaminations increases over time while sulphide also increases, which will give odors. (Madungwe and Sakuringwa, 2007)

The wastewater from laundry does not only contain chemicals, as shown in table 3, but also consist of products such as hair, dirt and fibers, which are examples of sources of solid material. These solid materials or amount of turbidity could give some information about the content of particles that could induce clogging in filters used for treatment of the water. Although the amount is expected to be low the problem should not be neglected. The reason is that the combination of colloids and surfactants could cause stabilization of the solid phase, due to the absorption of the surfactants on the colloid surfaces. The wash cycle from the washing machine has a significantly higher amount of turbidity that the rinse cycle. (Erikson et al, 2001) This is something to keep in mind when someone wants to reuse the wastewater from the laundry, since hair and other solid materials could cause clogging of the treatment system, especially when the system will be operating at low pressure. To achieve this collection of particles, flocculation or sedimentation of some sort needs to be created. Common methods for this is flocculation which are created by addition of chemicals that binds the particles, or sedimentation created by a flow though several steps where the particles sinks down to the bottom, an example is a tree-step sedimentation system. A filter is also needed to accumulate light particles that do not sink. (Welty et al, 2008) Another important aspect is the content of pathogens, infectious agents, such as faecel coliforms and faecel streptococci in the wastewater. The amounts of these pathogens are showed in table 3.

Table 3: The table shows the quality of laundry wastewater. (Christova-Boal et al, 1995)

Parameter	Range [mg/l]
pH	9.3-10
Color	50-70
Turbidity	50-210
Oil and grease	8.0-35
Nitrate [N]	0.10-0.31
Phosphorus [P]	0.062-42
Total alkalinity	83-200
Calcium [Ca]	3.9-12
Magnesium [Mg]	1.1-2.9
Sodium [Na]	49-480
Potassium [K]	1.1-17
Iron [Fe]	0.29-1.0
Zinc [Zn]	0.09-0.32
Copper [Cu]	0.05-0.27
Aluminum [Al]	1.0-21
Sulphur [S]	9.5-40
Silicon [Si]	3.8-49
Cadmium [Cd]	<0.01
Arsenic [As]	0.001-0.007
Selenium [Se]	<0.001
Chloride [Cl]	9-88
Total coliforms/ 100 ml	MPN[13] $2.3*10^3$-$3.3*10^5$
Faecal coliforms / 100 ml	MPN 110-$1.09*10^3$
Faecal streptococci/ 100 ml	MPN 23-<$2.4*10^3$

4.5 Reuse of washing water

The reuse of laundry wastewater have some different possibilities one of them are toilet flushing while another is outdoor application for irrigation, washing of cars and windows (Erikson et al, 2001) (Prathapar et al, 2005). These reuses refer to both treated and non-treated laundry water but focuses here are for non-treated wastewater.

4.5.1 Garden irrigation

The effects from irrigation on soil pH and the buffering capacity will be determined by the alkalinity, hardness and pH from the laundry water. The content of heavy metals and chemicals products will be of importance for the reuse of water. Laundry water is alkaline and has pH values in the range 8-10. (Erikson et al, 2001) Analysis of laundry water has indicated high levels of

[13] Most probable number

sodium, zinc, aluminum, carbonate, nitrogen and low amounts of faucal contamination. The nitrogen content is very low due to the fact that it is not found in the detergents, the small amount comes from sweat and other body fluids washed from clothes having nitrogen component. (Patterson, 2004) It is however important to consider nitrogen since it is one of the main reasons of eutrophication in local waters and serves as a problem when concerning for the local environment. (Palm, 2010)

The concentration of phosphate is generally much higher in countries, which have not yet banned phosphorus-containing detergents. Phosphorus is an essential nutrient to plant and is therefore usually not a big problem. The problems arise when the soil becomes saturated and therefore causes a potential leak to the groundwater. The high amount of carbonate/alkali in laundry detergent has a significant effect on the soil pH, especially when the soil pH exceeds 8-8.5 then micronutrient deficiencies. (Christova-Boal et al, 1995) However concentrated powders have less filler, which therefore have a lower salinity, and thereby less effect on the soil pH. (Patterson, 2004) Zinc as a metal ion has been found in the wastewater from laundry. Zinc occurs naturally in the environment but high levels of zinc in the wastewater might accumulate in the soil and cause damage to plants. Sodium is another nutrient that is harmful to plants if it is in a large amount in wastewater as described in section 4.4.1. (Christova-Boal et al, 1995) Table 4 shows the quality of laundry water and how clean the water needs to be, before being reused for irrigation. Standard A, if the water is to be used to irrigate fruits and vegetables, which are likely to be eaten raw. Standard B, it the water is to be used to irrigate fruits and vegetables likely to be cooked and eaten. (Prathapar et al, 2005)

Table 4: The table shows the quality of laundry water and the required treated water to be reused. (Prathapar et al, 2005)

	Laundry	**Standard A**	**Standard B**
PH	8.3	6-9	6-9
TSS [mg/l]	315	15	30
COD [mg/l]	231.3	150	200
BOD [mg/l]	179.7	15	20
Mg [mg/l]	60.84	150	150
Na [mg/l]	667.15	200	300
Zn [mg/l]	0.14	5	5

4.5.2 Toilet flushing

Water for toilet flushing is a relatively constant requirement throughout the year. The water used for toilet flushing must be of such a quality that it does not contribute to build-up of undesirable materials, mainly pathogens, in the cistern. There could therefore be a problem in using untreated laundry water for reuse to flushing the toilet. This is because of the small risk of spreading diseases, due to microorganisms in the water that could spread in the form of aerosols generated when the toilets are flushed. (Erikson et al, 2001)

5 Water treatment methods

There are many methods to treat water depending on how dirty the water is and what ambitions there are for the resulting cleanliness of the output water. These methods can be used separately or combined. Some methods are more comprehensive than others and some are meant for simpler applications. This study addresses several water treatment methods that are considered simple and cheap solutions for treating water. The studied water treatment methods are *Constructed Wetlands, Activated Sludge*, *Sand Filter* and *Peat Filter*. All these methods have similarities regarding the mechanisms. All are based on the function of mechanical rinsing and biological degradation, but all have different efficiency levels and design.

More advanced systems are deemed as non-feasible options and are therefore excluded. No particular degree of cleanliness is required for the output water as the reuse of the water will be determined subsequently to the MCA. The alternative of not treating the grey water at all is further discussed in section 7.3.

5.1 Small-scale ecosystems, Constructed Wetlands (CW)

A wetland is an area that's survival depends on the presence of water and it plays a role of managing and processing the water it depends on. The out coming water can be used for various things such as irrigation, drinking and sanitation. (LePage, 2011)

A constructed wetland, CW, is defined as a wastewater treatment system composed of a base container where natural (eco-system equal) processes occur; an example is shown in figure 8. All contain organisms of different complexity and the water flow is usually driven by gravity. The contaminants are in a CW removed by mechanical, chemical and biological mechanisms. (Cordesius and Hedström, 2009)

Figure 8: A constructed wetland assembled outside a school in an urban area south of Cochabamba (Cordesius and Hedström, 2009).

5.1.1 Different constructions

Constructed wetlands can be categorized in two main groups determined by where in the system the water is located, as shown in figure 9. Wetlands that carry the water horizontally in a waterbed were the wastewater is located at a constant depth with contact with the atmosphere are called free water systems, FWS. Systems where the water flows underneath the surface are called subsurface flow systems, SSF systems, and can divided into the subgroups of horizontal and vertical flow. (Bodin, 2013)

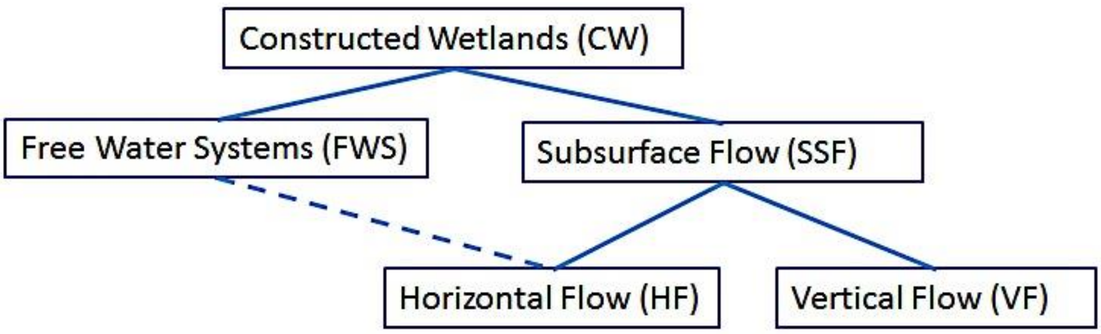

Figure 9: A schematic illustration of the categorization of different wetland types.

A free water system is not suitable in this project due to the risk of air contaminants, smell and giving a thriving environment for example mosquitoes in areas such as Cochabamba (Palm, 2010). Therefore SSF are the ones further investigated.

5.1.2 Sub Surface Flow Constructed Wetlands Mechanisms

The sub surface flow CW consists of many intertwined mechanisms and the whole system is a much complex one. As an example of the complexity the path of a single chemical can be described; where the first thing that occurs is a chemical oxidation of a dissolved compound, which makes it precipitated. This stops it from flowing further because of physical barrier due to the changed molecule and the physical properties that occurs. A precipitated compound can then be degraded in the rhizosphere and the process ends by an uptake of a plant in the system.

5.1.2.1 Physical Mechanisms

The coarse filtration process mainly consists of sedimentation where particles suspended in water are separated under the influence of gravity when the solution passes through a coarse filter. The efficiency of removing particles from water via sedimentation is described as an exponential decay throughout the height of the mechanical filter, so the top layers of the filter will contain more pollutants than further down. The choice of porosity is determined by the size of the gravel in the sand. Therefore, since filtration efficiency work as an exponential decay, clogging mainly occurs in the very top of the system. The clogging is primarily an effect of bio-film build up that arises when the filter does not have enough time to recover its porosity. A periodic flow of wastewater is found to be the most sufficient in avoiding a bio-film build up, this because of the time in between water pulses that allows the CW to recover. (Kadewa, 2010)

Further, Kadewa (2010) also studied different grain size for constructed wetlands and concluded that grain sizes of two to four mm in diameter were sufficient. Thus, the size contributed adequately to removal of suspended particles and also reduced the clogging risk due to the fact that the bed with this grain size became porous enough.

5.1.2.2 Chemical Mechanisms

The chemical processes take place at all the different levels of the wetland. There is an atmosphere component where components in the water are emitted from the water through mass transportation. Beneath the surface smaller dissolved molecules precipitate and gets stopped by physical obstruction. Other processes such as oxidation and reduction can give properties such as charge to dissolved and suspended particles. All these processes lead to either removal or digestion of an organism for the dissolved substance. The processes are strongly controlled and dependent on temperature since the rate of chemical reactions and the metabolism of microorganism's decrease with temperature. (Cordesius and Hedström, 2009)

5.1.2.3 Biological Mechanisms

The underlying mechanisms of the biological processes of a constructed wetland is that it uses a community of organisms such as bacteria, plats and single cell organisms to digest and break down the waste as a part of their metabolism in the water and thereby cleaning it. The majority of the biochemical mechanisms is bacterial, either by free or plant supported bacteria. The bacteria are especially capable of removing BOD (Biochemical Oxygen Demand), colloidal solids, nitrogen and specific organics. In turn the higher organisms, plants, can degrade the chemicals and nutrients further via uptake through their roots. The coexistence of plant and microbial degradation with their uptake processes takes place and is made possible due to the existence of a rhizospere. This is the microenvironment around the root of a plant where microbes and single cell organisms live. The fact that there is constant flow of water in this region helps the effectiveness of the degradation in the rhizophere and there are also the uptakes of nutrients for the plant, phytodegradation. (Kadewa 2010)

5.1.3 Nitrogen removal in CW

Removal of nitrogen is an example of a cycle that involves physical, chemical and biological mechanisms. The most important parts and mechanisms of the nitrogen cycle for a CW are:

- *Ammonification*; the decomposition of organic nitrogen to ammonium, NH_4^+, by heterotrophic bacteria and fungi.
- *Adsorption*; ammonium can bound to negatively charged soil particles in the gravel of the CW.
- *Nitrification*; the aerobic bacterial process in which ammonium is oxidized to nitrite and nitrate.
- V*olatilization*; ammonium may also be emitted directly to the atmosphere as ammonia gas, NH_3.
- *Diffusion*; the process was nitrate might be transferred from its water state to its solid state and form sediment.
- *Denitrification*; the transformation of nitrate to nitrogen gas, N_2.

Vegetation can in the CW assimilate inorganic carbon and turning them organic in forms of amino acids. However if the plats are not harvested the nitrogen will return to the system when the plant dies via decomposition of the plant. (Bodin, 2013)

Of these processes, the biological nitrification and the subsequent denitrification is considered to be the major pathway for removing nitrogen from a CW. (Environmental Protection Agency, 1993)

5.1.4 Phosphor removal in CW

Detergents are the largest source of inorganic phosphor in form of phosphate and in food residues as organic phosphate. Due to no gas phase for phosphor in the biogeochemical cycle, in contrast to the nitrogen, phosphor is mostly removed by adsorption or chemical binding to other complexes in the wetland.
(Bodin, 2013) Phosphor is also taken up by plants and microorganisms but at very low rates compared to the inflow of phosphor. Removal can however be enhanced by using a filter medium that has a larger capacity to bind phosphor, such as iron or calcium, it is however not possible to remove all phosphor by using only the gravel and its characteristics. An alternative method is using the chemical precipitation and trust in sedimentation of clusters of phosphorous

material. However, this will not lead to phosphor actually leaving the wetland. (Cordesius and Hedström, 2009)

5.1.5 Construction and Hydraulics

In general the constructed wetland should be an attempted design to imitate the processes of highest importance in the design. According to Environmental Protection Agency, EPA, in 1993 several points should be considered:

- Simple design for minimal maintenance
- Use natural energies, such as gravity for flow direction
- The design have to be appropriate for the local environment, integrate it with the natural topography on site
- The design should be aesthetically appealing. Do not over engineer, for example in terms of sharp edges. Design for function not form, for instance if the first plants does not sprout the wetland's remaining functions shall still be intact

5.1.6 Advantages and Disadvantages

Difficulties and advantages of the mechanical mechanisms are the same positive and negative effects of that of sand filter for example the ability to remove suspended particles but also the problem of clogging. It is important to note that CWs effects are influenced by many parameters. For example are the climatic conditions such as solar radiation and temperature, which in turn affect evapotranspiration, ground evaporation and plant transpiration. So how much water that can be extracted from the system is correlated with in what climate the CW is implemented. (Bodin, 2013)

One of the most important positive social aspects of having a CW is the aesthetic value that is added with one. The argument that adding a CW will enhance the attractiveness of the landscape (Environmental Protection Agency, 2000) is a strong one and should be considered to be weighted heavily.

Difficulties have been shown of water bypassing the wetland in making channels that will flow directly to output water, and there is also a possibility of clogging if a pre-treatment to remove larger particles and fatty acids does not work successfully. However the latter is not a significant problem in this case whereas the water is only grey water. (Cordesius and Hedström, 2009)

Discussions on many fronts are made on the pros and cons of a CW. Many can be derived down to the *Handbook of Constructed Wetlands* (Environmental Protection Agency, 1995) were benefits and disadvantages were discussed, as seen in table 5.

Table 5: According to the Environmental Protection Agency, EPA, Handbook of Constructed Wetlands (1995), benefits and disadvantages of constructed wetlands are showed.

Benefits	Disadvantages
Can be built so that they fit pleasantly in the surrounding landscape, an aesthetic improvement to open spaces	Requires larger amounts of space than conventional water treatment
Can tolerate non constant flow of water	Require a minimum amount of water and cannot be drought for longer periods of time.
Environmentally favorable	Biologically sensitive to certain toxics
Less expensive than other treatment options	
Operating and maintenance costs are low - maintenance is done periodic and not continuously	

5.1.7 Implementing an Applicable System

Several systems have been implemented for household uses in both privileged and underprivileged areas. The project report from Cordesius and Hedström (2009), shown in figure 8, was used as a background project in implementing a functional system. They installed a gravity driven horizontal subsurface flow CW, called PTAR1, which was planned to cost 2 675 USD and ended up costing 3 130 USD due to technical difficulties and need of additional equipment. This system included a grease trap, a septic tank, the actual wetland, an effluent tank and pump to collect water, pipes, gravel and lining with high density polyethylene. The PTAR1 system was constructed and implemented for the wastewater from a school located in a peri-urban area outside Cochabamba, and should be considered as a feasible option for treating grey water.

Costs will rise if the size and capacity of the wetland is increased. Some parts, such as a grease trap and effluent pump, are costs that vary in sections depending on the water volume. The most expensive part, according to Cordesius and Hedström (2009), is the high-density polyethylene lining which increases directly to the size of the wetland. A possible major cost, which would probably be the largest, is if land area needs to be purchased. Further costs in advancing the total system can be installing a recirculation pump that pumps parts of effluent water back to the top of the wetland to avoid drought.

5.2 Activated sludge

Biological treatment of wastewater is a way to handle nutrients, chemicals and organic substances in sanitation facilities. Sludge consists of living organisms that use these unwanted compounds as substrate, usually as a part of a larger treatment process. (India sanitation portal, 2011)

5.2.1 System and function

Biological treatment of wastewater is usually used as a part of a bigger system, where other functions help in the process of rinsing the water. Water treatment in big sanitation facilities usually consist of three parts; mechanical, biological and chemical cleaning, where the biological step involves activated sludge. The sewage has to be cleansed in several steps to process all the different kinds of pollutions and dirt. In the mechanical cleaning, the water is transported through different strainers and grids to rinse out particles and solid objects. Techniques for this can also involve sand traps and sedimentation tanks. (Gryaab)

The chemical step of the treatment process is based on an addition of chemicals that binds to the phosphate of the wastewater and then sediments to be separated from the rest of the liquid. Normal chemicals to use are iron chloride and aluminum ions. (Gryaab)

The biological step is where bacteria and other organisms are used to break down different compounds like organic materials and nitrogen. The most common process to biologically handle wastewater treatment in bigger facilities is by activated sludge. (Topasvatten, 2008 a)

Activated sludge breaks down biological material and is the key of biological water sanitation. The biomass of the sludge treats the sewage in a process where organic material is reduced in presence of oxygen. It is called activated because it consists of particles, bacteria and protozoa that metabolizes on the organic waste. These processes take place in a mixture of sewage and activated sludge. The sludge normally exists in form of flakes. (Lenntech, 2014 a)

Activated sludge containing a biomass of different organisms is mixed with the sewage to create a mixed liquid where the reactions happen, before the sludge sediments for the cleaned supernatant to continue to the next step. Nitrogen goes through nitrification, and then in non-aerated zones it is denitrified to create nitrogen gas. This can occur in the process at the same time as the chemical cleansing, which is called a simultaneous precipitate. (Gryaab)

The living organisms in the sludge demand large quantities of air, which is very energy consuming to produce. To create the environment needed compressors and airing by bubbles is used. Tubes with holes are usually situated in the tanks, to spread the oxygen evenly and though the entire mixture. The oxygen is needed by the bacteria and other microorganisms in the system to live and grow. (Lenntech, 2014 a)

After the cleaning by the sludge it is necessary to separate the sludge and waste from the cleaned water. This is done in a separate tank for sedimentation where the particles of sludge flakes are separated by settlement and the supernatant fluid can continue on from the top of the tank. (India sanitation portal, 2011)

For the activated sludge culture to maintain a functional growth in the cleaning step there has to be some recirculation of sludge from the sedimentation tank to the cleaning process. To get a good result there has to be enough bacteria in the mixed liquid to treat the water, but still not enough to create a lack of oxygen. Therefore some of the sludge is reused to keep the living culture prosperous (India sanitation portal, 2011), this is called the return activated sludge (Lenntech, 2014 a).

To reach a constant sludge age some biomass has to be removed, and not reused. This is called excess or secondary sludge and is the biomass after sedimentation that does not recycle back to help the cleaning process. The water from the sedimentation tank continues on to further steps of treatment, depending on the facility. (Lenntech, 2014 a)

The primary goal of biological treatment is removal of dissolved and suspended organic matter from wastewater. The organic compounds are used as substrate for the microorganisms in the sludge. Biological treatment is also capable of removing other wastewater components like suspended solids, nitrogen, phosphorus and heavy metals. (Lenntech, 2014 b)

Nitrogen is cleaned in two steps in bio sanitation systems (Gryaab).
According to a report from 2013, by sewage treatment facility Gryaab in Sweden, the cleaning efficiency of nitrogen in their facility was 73 percent during 2013. This was calculated as a medium value for the months November 2012 to October 2013, and was presented in a monthly report made by the company. (Mattson, 2014)

In an example from a smaller system made for household usage the nitrogen cleaning efficiency is 60-80 percent in the biological step. If combined with chemical cleaning in simultaneous precipitate, the phosphate is reduced by 90 percent. (Topasvatten, 2008b)

5.2.2 Demands on the system

To keep the system healthy and efficient the microorganisms need optimal conditions to keep a good population with the cleaning properties required. The environment in the process tank therefore needs to satisfy a list of demands concerning the survival of the sludge. (Lenntech, 2014 a)

One of the demands is the need of recycled sludge too keep the biomass population to a sufficient size. Another important function for the survival of the organisms is the constant aeration of the mixed liquid. If this is not done sufficiently, the sludge will not survive. The amount of substrate for the biomass needs to be kept at a good level for the sludge to keep the population size. If the substrate is too abundant the cleaning result might not be satisfying. (India sanitation portal, 2011)

5.2.2.1 Diversity in designs

There are many different sizes and solutions that use biological cleaning with sludge on the market. The concept of sludge cleaning water by consuming undesirable content as substrate is used in large scale in sewage treatment facilities and in smaller versions of a few cubic meters for household usage.

5.2.2.2 Frequent Complications

For the system of activated sludge to work there has to be a steady flow of incoming wastewater. If there is a sudden rise in inflow the amount of sludge will not be enough to clean the new volume of water. The culture of sludge would also grow rapidly with the excessive amount of substrate from the inflow, and starve when the inflow comes to a stop. This would give a great imbalance to the system, and have an impact on the results. To help the situation and even out the inflow of water from an uneven source a separate tank can be connected, from which the flow is constant. (Topasvatten, 2008 c)

For waste management to work there has to be a working faze of separation in the process where the sludge is taken from the water. When this is performed in an inadequate order the sludge can exit the separation tank and follow the stream. This phenomenon is called sludge loss and can be the cause of disturbing the cleaning process and creating unpleasant odor. (Topasvatten, 2008 d)

Technical sludge loss can happen if the amount of sludge is too great in the process, or the tank is not protected from sudden flows of incoming wastewater. The system is quite sensible to changes of the volume of inflowing water.
Biological sludge loss can happen when there is a disturbance in the composition of microorganisms, which for example can decrease the sinking abilities and create floating sludge. If there is not enough oxygen in the water the ability to create flakes of sludge can be decreased, usually depending on the water quality. (Topasvatten, 2008d)

5.2.3 Applications in a functional system

A realistic concept of activated sludge for household usage is based on some sort of mini-sewage treatment facility where the biological cleaning is combined with chemical treatment and possibly a sand filter. These can be bought in small sizes with the purpose to stand in a room connected to the wastewater inflow, or placed in the ground as an alternative for plumbing.

The cost for these kinds of solutions may be different depending on where in the world they are bought, and the cleaning efficiency demanded. As an example: the cost for a single household mini-treatment unit from a specific company in Sweden is 40 000 Bs and 52 000 Bs for normal and high level of cleaning. These prices include tax but not installation. The units do not need advanced maintenance, but a change of chemicals and rinse of filters once a year. [14]

With the use of the more expensive option the treated water would gain high efficiency values that are satisfactory regarding BOD, Phosphorous and Nitrate (IFO Vattenrening). Figure 10 shows an example of a mini-sewage treatment unit, with a treatment system where the biological cleaning steps are done, with a connected sludge separator to keep the cultures and levels constant, as described earlier in sections 5.2.1.and 5.2.2. This is just one of many designs for mini sewage treatment units.

[14] Sells person (Serviceline, IFO vattenrening AB) telephone conversation to telephone number +46 8 445 95 4 on 2014-03-13.

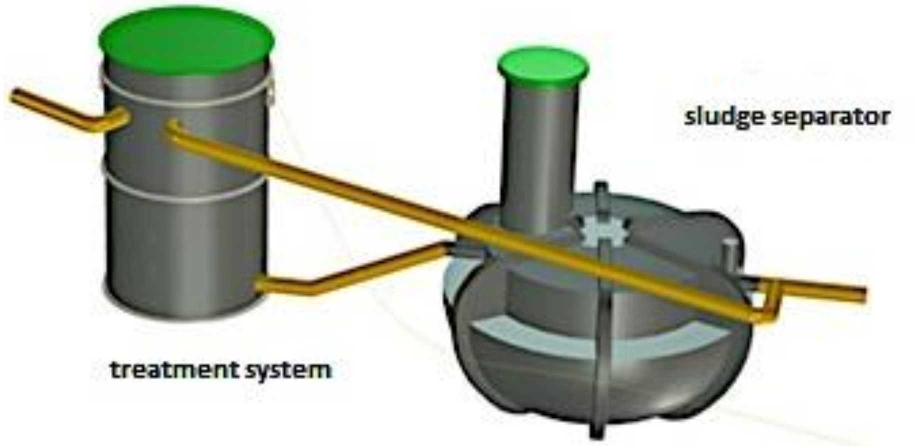

Figure 10: Example of a working mini sewage treatment system, with a connected sludge separator. (The picture is modified with removal and translation of text) (IFO Vattenrening)

5.2.4 Advantages and Disadvantages

In general the biological wastewater treatment is the most efficient and economical way of removing organic pollution from grey water (Lenntech, 2014 b). A mini-sewage treatment unit is very effective in reducing unwanted substances in wastewater, and gives a reliable result. The treated grey water is of high quality and hygienically safe so that it can be reused, alone or combined with rainwater, for toilet flushing water, laundry washing or irrigation purposes. (Paris and Schlapp, 2010) But it might not be applicable in every situation due to different quality demands on the treated outflow of water, or limitations of space or funding.

The specific materials used in a system of biological cleaning are not necessarily expensive, but the realistic usage for a household would probably be of a complete mini-sewage treatment unit, not only the biological cleaning step. This would give a substantial cost to first obtain the system, and then there would be a cost of chemicals for yearly refills and maintenance. In the practical example of Cochabamba, there might not be prerequisites in place for such a solution. There might be difficulties both in the possibility of finding these products on the local market, and the ability of the customers to afford it.

5.3 Sand filter

Purification of water by sand filtration is common and it can be done in various ways, but the main idea is the same. The water passes through sand to eliminate particles and unwanted materials in a mechanical way. Usually a sand filter includes a tank made of concrete or plastic, and the shape can be both rectangular and circular. Further, the tank consists of sand, gravel and a drainage system to collect the purified water. Sometimes there is also a flow regulator to control the velocity of the filtration, which usually is from the top to the bottom, but it could be done conversely. (Huisman, 1974)

The sand should have a specific size of the grains and it is important that it is clear from organic material, calk and iron. There are two dominating ways of sand filtration, fast filter and slow filter.

5.3.1 Fast sand filters

Fast sand filters have a shorter process, where water runs through the filter quite quickly. The process is mainly based on mechanical cleaning of the water that flows through, where particles are removed and the product is collected after the filter.

A filter for this fast process is made of a waterproof container, holding a thin layer of gravel at the bottom, and a thicker layer of sand on top. A deeper layer of sand gives a better filtration, and therefore a higher cleaning efficiency. A simple solution of this is demonstrated in the figure 11 below.

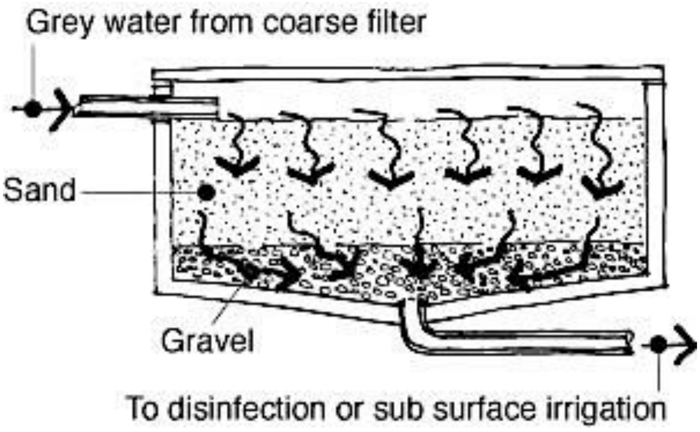

Figure 11: Representation of a simple fast sand filter model. (REUK - The renewable energy website, 2014)

5.3.2 Slow sand filters

Slow sand filters, or bio sand filters, are used to clean water by mechanical purification and biological processes, which reduces the amount of organic material and bacteria. The water is filtrated when it passes the sand by gravity. The larger the sizes of the grains are, the faster the water is filtrating through the sand. (Huisman, 1974) The sand is tiny and works without chemical pre-treatment, as chlorine and flocculation. (Andersson, 2009) Since slow sand filters have a biological process, which is needed to remove nutrients from the water, it is further studied in this project.

5.3.2.1 Construction and function

One example of a construction of slow sand filter shows in figure 12. The depth of the sand bed and the size of the grains in a sand filter are important, due to the efficiency of the filtration. Smaller gaps between smaller grains and a larger surface area make the absorption bigger. (BioSandFilter.org, 2014) For example a depth of 0.6 meters of sand with grains of 0.15 mm diameter has the same particle surface area as a depth of 1.4 m of sand with grains of 0.35 mm (Huisman, 1974). If the size of the sand grains is too small, this will result in clogging. The recommended size of the grain should be in the interval of 0.15-0.5 mm. The depth of the sand should be about at least 0.5 m for slow filtration, but it is common with a depth of more than one meter. In slow sand filters the biological activity occurs at this specific level of depth. (BioSandFilter.org, 2014) A slow filter is often called bio sand filter because it contains biological activity. During the filtration a layer of biological material is build up, called schmutzdecke, and it consists of bacteria, unicellular organisms and larvae. Particles and organic materials, even bacteria, is collected and decomposed here. Nitrogen compounds are also broken down and oxidized in this stage. (Huisman, 1974)

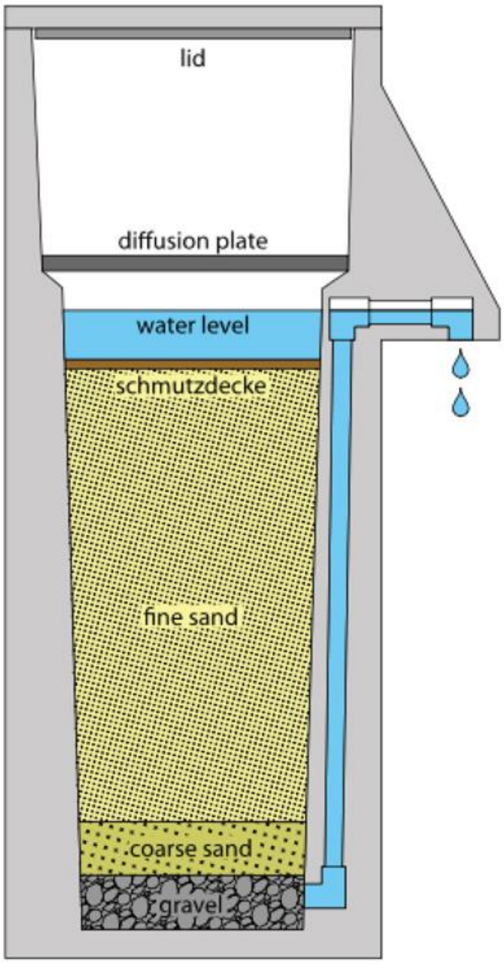

Figure 12: An example of a slow sand filter. (Water from your quarter, 2012)

Depending on the incoming water, the biological activity is developing in three to seven days from the beginning of the filtration (Andersson, 2009). The content of the incoming water should not vary, because the bacteria in the biological layer adjust for the water that is filtered (Huisman, 1974). The bio layer needs oxygen to operate. Flowing water brings dissolved oxygen and when the filtration is paused diffusion occurs with oxygen from the air. (BiosandFilters.info, 2011)
Under the layer of sand, there is a layer of gravel. The amount of gravel is depending of the drainage system where good drainage efficiency requires a lower amount of gravel. The stones are supplied to prevent the sand from clogging the outflow pipe. (Andersson, 2009)

The water level has to be approximately five centimeters above the layer of sand, which is important due to the fact that a higher level results in a lower oxygen level, which has a negative effect on the bio layer. On the other hand, it is not good if the level of water is less than five centimeters because there is a risk of the sand layer dries out, and thereby killing the bio layer, especially in warmer climates. (Biosand Filters.info, 2011) There should be a minimum of 0.5 mg/l dissolved oxygen in the incoming water to avoid inferior result of purification. (Andersson, 2009)

The air temperature is important since the efficiency of the purification decreases in lower temperatures, considering the rate of chemical reactions and the metabolism of microorganisms. At temperatures below two degrees Celsius, the system should be protected to ensure good results, for example the filter could be covered to prevent heat loss. (Huisman, 1974)

The velocity of the filtration is usually 0.1-0.4m^3/h per square of surface and it is depending at the gravitation and the depth of the sand bed. (Huisman, 1974)

5.3.2.2 Use

Slow sand filters can be used for weeks before maintenance is necessary. The time for rinsing the filter depends on several factors, for example the degree of impurity, the velocity of filtration and the volume of water flowing through the filter. (Andersson, 2009) One easy method to clean it is by scraping away a layer of one to two centimeters on the top by hand, when the water over the bed is almost dried out. The bed should not be completely dried out, since that would greatly impact the bacterial recovering period after rinsing. A regrowth period is necessary for the system to regain its function. About one or two days are required for creating a new bacterial layer and during this time the water should not be used. Two to three percent of the total amount of water is practically used for cleaning the filter. (Huisman, 1974) Another maintenance method is "back flushing", where the filter is rinsed by water passing the filter in the opposite direction.

5.3.2.3 Purification

The slow sand filter reduces the amount of bacteria with average 81-100 percent. Phosphorus and nitrogen is also removed effectively from the water, but the amount of reduction is hard to evaluate. (Andersson, 2009)

5.3.3 Advantages and disadvantages

The sand filter has a sustainable design. There is no chemicals added or use of electricity and it can be constructed of local, simple materials, which benefits the costs of production. Furthermore there is no other maintenance cost, which limits the required funding to manufacturing costs. (Schaub, 2010) The system is easy to use since the maintenance work, consisting of cleaning of the sand beds, is minimal and can be done manually.

There are also disadvantages with sand filters, such as the low effect they have on viruses. Another obstacle is the fact that sand filters require space because of the low water velocity, especially with large amounts of water to purify. Therefore implementation can be difficult in situations where there is lack of space. (Schaub, 2010)

A disadvantage of slow filters is that the system is very dependent on the relatively high inflow rate and constant volumes. As the biological layer becomes stagnant in lack of water, the system is unstable in situations where inflow is unreliable. This is on the other hand a big advantage in the use of fast sand filters, where the system because of the non-existent bio layers, is not dependent on constant water flow to remain functional.

5.3.4 Application in real life

The slow sand filter is used as a part of the process in big water treatment plants, but also to treat pool water or in smaller scale in developing countries for household usage.

There are several practical examples for sand filter system used in developing countries in aid projects. The Swedish foundation "Ancla" is working with a water project in South America and has made a version of a slow sand filter called "two-step system", see figure 13, which was tested in among other places Amazonas in Colombia. (Ankarstiftelsen, 2013 a)

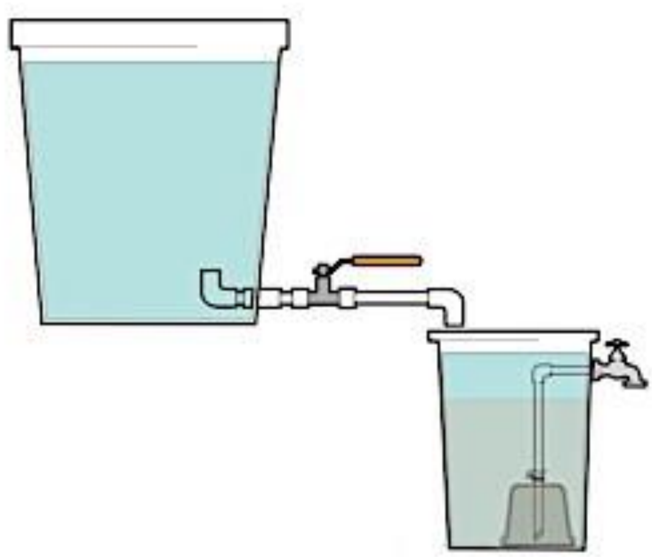

Figure 13: Illustration of a two-step system. (Ankarstiftelsen, 2013 a)

Also a "three-step system" has been developed and built in Amazonas, with focus on treat surface water and rainwater, to drink water. (Ankarstiftelsen, 2013 b)

In a realistic concept of slow sand filter the system demands a relatively slow and constant flow of wastewater. Therefore, the system needs to include an equalizing tank, where the irregular inflow is collected and kept constant towards the sand filter to keep the water level of the bio-filter even. This demands a rather big inflow of grey water to the system, in order to avoid lack of water.

The faster sand filter does not need a first tank to even out the flow. While the quality of the resulting water is not the same, due to the lack of treatment of nutrients, the system is less sensitive. The concept is not dependent on constant inflow of grey water. Both systems gain from a mechanical rinse of the wastewater before the treatment starts, for example in the form of a filter bag as seen in the figure 14. The systems also gain higher cleaning efficiency by addition of chemicals for sedimentation, in a step connected to the filter. The same result can also be achieved without chemicals by connection to a sedimentation tank or flocculation chamber to the system. (Norberg, 2014) In the specific case compared in the MCA analysis, slow sand filters will be discussed, as they provide better treatment.

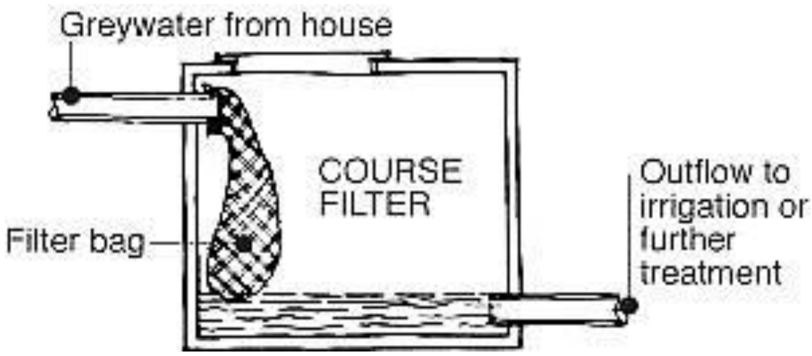

Figure 14: Example of a rinsing solution using that can be used in combination with a sand filter. (REUK- The renewable energy website, 2014)

5.4 Peat filtration

Peat is a mixture of decomposed plants and can be useful in water treatment filters. There are existing products using the cleaning ability of peat to treat water in a smaller scale.

5.4.1 Function

Microorganisms on the surface of peat use incoming wastewater as nutrition (Avloppscenter, 2014). Peat has a good potential to work as a sorbent for both organic pollutants and metals due to the high percentage of organic content and therefore be it can be useful in passive filter barriers to clean water for a low cost (Larsson et al, 2007). Purification methods using filters consisting of peat mixed with ashes have previously been used successfully in for instance cleaning leaches from landfill (Kängsepp, 2008) and wastewater from carwashes (Söderlundh, 2010).

5.4.2 Installation and use

There are products designed for smaller houses, which use peat to clean grey water. One example is Uponor-BDT Easy grey water filter, which is about one cubic meter and has a capacity of 500 liters per day. One complete set cost
15 500 Bs. The product makes water clean enough to be released in the nature and can be used for irrigation. (Avloppscenter, 2014) The maintenance includes changing the peat, which has to be done after 100 days of use. For installation no machines or special tools are required and the weight of the system is 35 kg without any peat loaded. (Uponor, 2011)

5.4.3 Environmental affects

Peat is created when plants decompose at wet areas with low or no oxygen supply. It is classified as slowly renewable biomass which means that it takes less time to create than for example fossil fuels like oil but longer than renewable energy like wind power. Extraction of peat has environmental and climate impact since vegetal layers are peeled off and the actual area is dewatered, which affect many of the species negatively. (Energimyndigheten, 2009)

When the filter has been used it is classified as waste, which today is burnt to extract energy. The peat is almost completely burnt which means that the energy is highly extracted but the ashes, due to the mass, are almost unchanged through the complete cycle. The ashes can be used at for instance building roads, which would decrease the impact on the environment, though it has to be clear that a potential leach of dangerous substances can impact the closest area negatively. (Olsson, 2008)

6 Multi Criteria Analysis for water treatment methods

A Multi Criteria Analysis, MCA, is a method to compare several alternatives through weighing and scoring several criteria. Through this, different decisions are made forming a complex structure for evaluating comparable choices. (Argyrous, 2009)

The following MCA is a comparison of the presented treatment methods; wetlands, activated sludge, slow sand filter and peat filter in the context of treating grey water from a washing machine. A limitation in the analysis is that the different capacities of volume of treated water in the systems are not considered. This is because the amount of water treatable for a system varies with the size and expansion of the system. The systems in the MCA are all considered to have sufficient capacity. The treatment method with the highest MCA score is further analyzed regarding what sort of activities the purified water can be used for, since the exact cleaning efficiency can be determined first after testing it.

6.1 Criteria

The parameters for the MCA are selected in a way where focus is the possibility of implementation. Therefore the aim of this analysis is to evaluate the sustainability in terms of economic, environmental and social aspects. Because the goal of implementation the investment and maintenance costs together with the simplicity of the system are viewed as important factors. The content of the water is important for the reuse of water in both environmental and economic aspects. Thus, the three main topics that have been chosen are *cleaning ability, usage* and *resources* where each of the topics has three parameters each. These topics vary depending on each other regarding the aim and are therefore deemed to cover the purpose.

6.2 Weighting and scoring

Both the topics and the parameters are weighed with different values due to significance. Each parameter is also weighted with different values according to ability for that parameter. The three different topics; *cleaning ability*, *usage* and *resources* are weighted as one or two, while the parameters are weighted from one to three, due to significance compared with each other and external factors, like conditions in actual area. All the treatment methods are then scored from zero to five points, according to the reference of what the outmost points mean for each parameter. The total weighting and scoring system plays a significantly role in how well the treatment method can be successful in a laundry concept in Cochabamba.

6.2.1 Cleaning ability

The ability to clean water is important in both hygiene and environmental aspects. To be able to reuse the wastewater, the treatment method has to reduce *chemicals, pathogens* and *particles*. However, depending on what the water is reused for, the importance of water quality differs. Since the way of reusing the water is not fixed, the weight of cleaning ability is set to one.

Chemicals include nutrients such as phosphates, nitrogen and organic compounds but also other dissolved chemicals such as ions. The chemicals are important to reduce from the grey water from an environmental point of view because this is a factor that greatly limits the reuse of the water. The weight of this parameter is therefore three.

Pathogens consist of viruses, bacteria and other microorganisms harmful for human or other higher organisms (Bender, 2009). Since water from a washing machine is grey water, and not black water, the amount of pathogens and in turn the need to remove them are not significant and therefore the weight is set to one.

Particles is in the context of laundry grey water larger units of for example sand, fiber of garments and gravel. Since most particles are not dangerous and have no specific environmental impact, the weight is set to one.

Chemicals, pathogens and particles are all graded with the reference that zero points is unaltered water and five points is as clean as potable water.

6.2.2 Usage

Usage is an important factor regarding the possibility of implementation due to acceptance and use of the system. To create a feasible concept, the treatment method needs to be long lasting and relatively easy to operate. The usage criteria contain the parameters *robustness*, *maintenance* and *user friendliness*. The topic is however not deemed as important as the parameters of resources and is therefore weighted as a one.

The factor *robustness* contains life expectancy and economic sustainability for the treatment method. It may be problematic if the system breaks and spare parts are needed. Since there is a focus on successful implementation, the system needs to be easy to operate and robust, therefore robustness is weighted three. Robustness is graded with the reference that zero points is a system that is very sensitive for outside effects and five points is a system that is almost unbreakable.

Presumably, the factor *maintenance* will not be a major concern because of the possibility to instruct the users to maintain the system. There will hopefully be an interest to be involved in a solution that might benefit the residents; therefore maintenance is weighted as one. Maintenance is graded with the reference that zero points are maintenance every day and five points is no maintenance at all.

User friendliness regards social acceptance and in what way the system will impact the residents' daily life. A socially accepted and attractive system will make the implementation more successful; therefore user friendliness is weighted as two. Social acceptance is graded with the reference that zero points is when implementation is impossible because the system is not accepted and five points is when the system is attractive and desirable.

6.2.3 Resources

Parts of Cochabamba suffer from great poverty and also the amount of available land is limited. To achieve a successful implementation the system needs to be a low cost alternative and not demand too much space. The weight of resources has been set to two this because it is the most important part of the topics to make the concept feasible, due to the financial situation in Cochabamba. Resources are divided into cost of construction, cost of operation and land use.

Cost of construction is the cost of implementing the system. This includes expenses such as transport, material, instructions and labor of construction. Since financial resources are limited, the weight of cost of construction is therefore set to two.

Operation cost is the costs needed to run and repair the system. In a long-term perspective it is preferable to have low continuous costs. This is considered to be more important than the cost of construction due to the fact that financing over time is usually harder than requiring a larger one-time expense that could be sponsored or provided grant for. The weight of cost of operation is therefore set to three.

Scarcity of available land results in importance of a system that is efficient regarding *land use*. A system that requires a relatively large area will bring both economical and practical difficulties to implementing the system, since the land is expensive in the urban area. The weight of land use is therefore set to two.

Cost of construction, operation and land use are all graded with the reference that zero points is too expensive to implement and five points is minimal costs.

6.3 MCA score for water treatment systems

The calculation is made by setting scores on the parameters for each treatment system, using the literature study texts from chapter 5. Each score is then multiplied with its corresponding weight. The result is added up for each topic and then again multiplied with its corresponding weight. The total score is a summation of these weighted scores. The scores, weights and results for each system are all presented in table 6. For a calculation example, see appendix 3.

Table 6: Table over the result from the MCA of water treatment systems.

MCA-Water treatment system						
Criteria	Topic weights 1-2	Parameter weights 1-3	*Constructed Wetlands*	*Activated sludge*	*Slow sand filter*	*Peat filter*
Cleaning ability	**1**					
Chemicals		**3**	3	4	3	3
Pathogens		**1**	2	2	2	2
Particles		**1**	4	4	4	4
			15	18	15	15
Usage	**1**					
Robustness		**3**	2	3	4	4
User friendliness		**2**	5	4	2	3
Maintenance		**1**	4	2	3	3
			19	17	20	21
Resources	**2**					
Cost of constructions		**2**	3	1	4	3
Cost of operation		**3**	5	2	3	2
Land use		**2**	1	4	4	4
			23	16	25	20
	-	**TOTAL**	**80**	**67**	**85**	**76**

6.4 Multi criteria analysis results

The method with the highest score is slow sand filter, which is deemed as the best solution. This is based on a number of factors, but mostly it depends on the low use of resources. Since use of resources is weighted highly in the analysis this gives this method its high result. The solution is considered to be simple, affordable and space efficient.

The second best solution according to this MCA would be a constructed wetland, which also is effective in the use of resources. The problem is the extensive amount of space required. If high results with no limitations in land use were the conditions of requirements, then wetlands would have been the best solution. In the specific case of the studied area in Cochabamba, land use is an important factor, which is why resources are weighted highly in the analysis.

Activated sludge is a very effective system of wastewater treatment. A mini-sewage treatment facility would have been a good solution in an industrialized country where resources are less significant, and the products are more easily available. In the MCA it is deemed too expensive because the product might not be available in Bolivia and if that is the case, it is also too complicated without service support of a manufacturer.

Peat filter is harder to maintain than sand filter, since the entire filter needs to be replaced every six months, this demands a lot of material. The access to correct materials is not dependable in the case of the studied area in Bolivia, which results in slightly lower points in the category for resources.

7 Technical solution

Presented in figure 15 is the laundry concept as a whole system. This is presented with a schematic flow chart of the water in the system. The main components; washing machine, drying, water treatment method and different reuses are presented as way points.

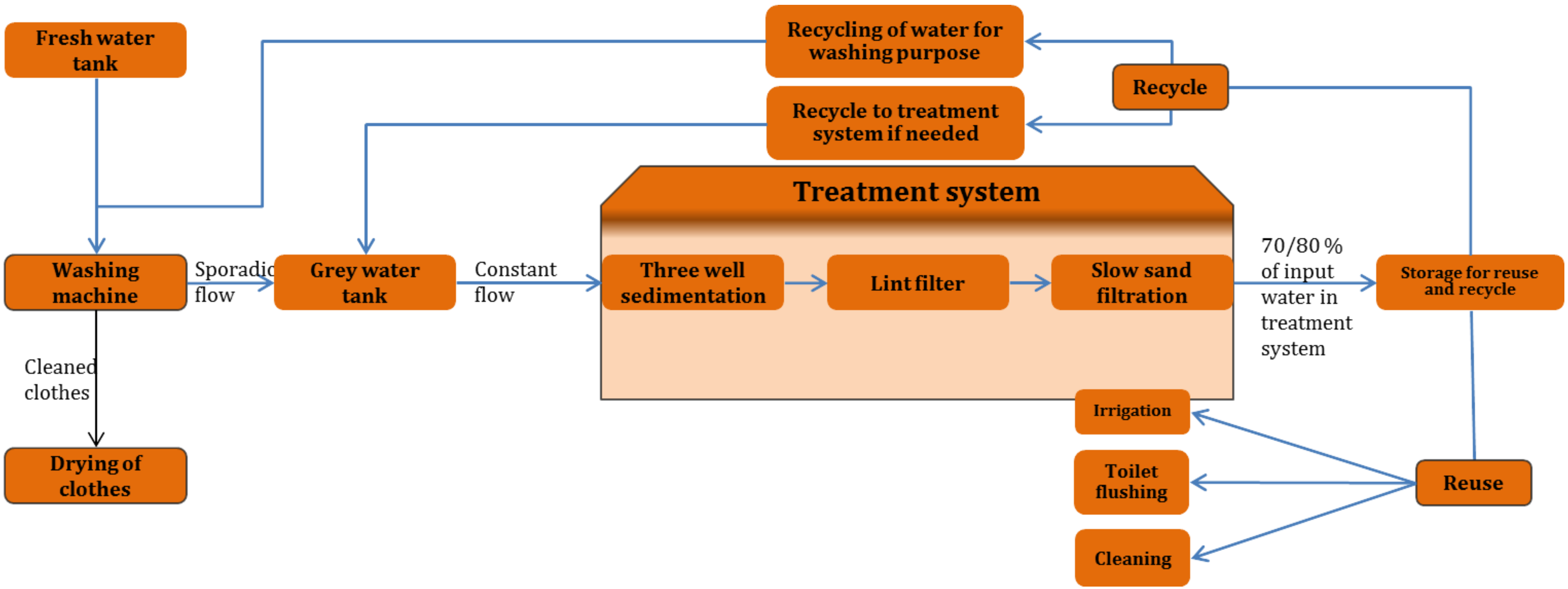

Figure 15: Schematic illustration of the flow of waters though the total concept. The whole concept could be implemented in a business or a self-service solution.

7.1 Washing machine

The concept will consist of a front loaded washing machine since it uses less water and energy than a top loaded one (Bluejay, 2013). If there is a tank placed on the roof, the machine can be connected to the water supply through a hose. This would also give a pressure of inflow in the machine from the height difference. As mentioned in chapter 4.3, the used washing machine is assumed to have a capacity of eight kg of laundry items and a water consumption of 56 liters per washing cycle, the cost for such a machine is assumed to be 3 800 Bs. Reasonable value for energy consumption is 1 kWh per washing cycle (Göteborg Energi).

7.2 Water treatment solution

The water treatment method of the laundry concept is based on a slow sand filter, since it was selected from the MCA as the best option, as shown in chapter 6. The treatment process also includes a filter and a three-step sedimentation system, in order to pre-treat the wastewater to avoid clogging of the sand filter. These components will together provide a cost-effective and simple treatment method for laundry wastewater. The cost for the water treatment system that is used in the economic estimations is assumed to be 10 000 Bs.

First in the wastewater system, there is an open tank that receives the sporadic outflow of wastewater from the washing machine. The tank is operating according to the Bernoulli equation that describes the variation of the elevation of liquid, velocity and pressure of outflow in a container, where the velocity is depending on the elevation of water. The Bernoulli equation is seen below as equation 1:

$$gy_1 + \frac{v_1^2}{2} + \frac{P_1}{\rho} = gy_2 + \frac{v_2^2}{2} + \frac{P_2}{\rho} \tag{1}$$

This is simplified as $v = \sqrt{2 \cdot g \cdot y}$, where g is gravitational acceleration and y is elevation of water (Welty et al, 2008). This will make the pressure and outflow velocity more even than from the washing machine. The wastewater flows into a three-step system that collects the particles after which, it flows through a mesh that filters floating fibers. The tree-step system acts like an equalizing point, which makes the incoming flow from the open tank constant into the sand filter. In the slow sand filter the bio layer treats nutrients and organic compounds and the sand filter gives a mechanical rinsing of particles, which is shown in figure 14. The water is collected from the sand filter at the bottom of the construction, since it is the force of gravity that drives the flow through the system.

A faucet is placed at the same height as the water level in the sand filter with the system in a stationary state, without inflow. Due to the pressure principles of Bernoulli, the level will be the same in the faucet as in the sand filter, because the same atmospheric pressure applies in both places. This means that once water is added to the system, the water level will rise above the faucet height creating pressure enough to extract water from it. In the Bernoulli equation, equation 1, two pressures are described, and can be negligible in this case as they are both atmospheric pressure. This results in equal elevation of water in both parts of the system, and therefor also the same velocity as showed below.

$$gy_1 + \frac{v_1^2}{2} + \frac{P_{atm}}{\rho} = gy_2 + \frac{v_2^2}{2} + \frac{P_{atm}}{\rho} \rightarrow \qquad (1)$$

If $gy_1 = gy_2 \rightarrow v_1 = v_2$ (Welty et al, 2008)

If there is an inflow in the system, a higher pressure will be created in the sand filter, due to the water pillar. The outflow will have the same velocity as the inflow in the system, and this will prevent drying out the biological layer, since water will only leave the system if there is an inflow. From the faucet the water can then be collected into a small tank.

The system can be constructed in many different ways, using the same principle. If it is built on site local materials can be used. One way of executing the tree-step system could be by placing three pierced buckets on different levels in a slope, as shown in figure 16. Between the buckets, for example, guttering can be placed to lead the water to the next bucket. This way of constructing the water treatment system was performed in Colombia in 2006. (Blad and Ringsby, 2013)

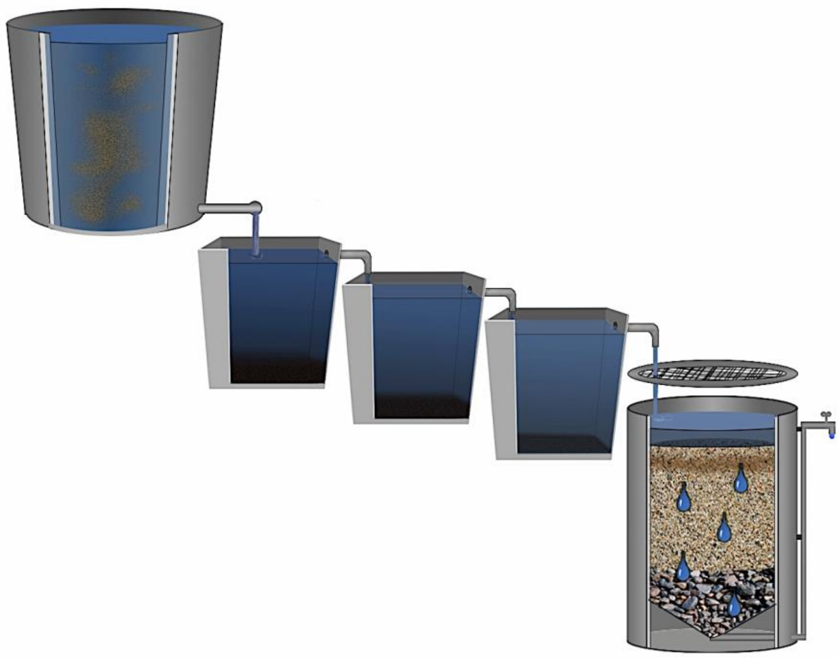

Figure 16: The technical concept based on the sand filter solution, with a connected tree-step sedimentation system and a filter. Note: Illustration by Johan Swanberg (2014).

The maintenance of the system includes a rinse of the filter and the three-step system, and removal of the top centimeters of the sand filter, as described in section 5.3.1.2. There also needs to be an addition of sand to keep the level constant, but the materials needed for this are minimal. The sand removed from the top can be cleaned and reused.

As described in section 5.3.2, a slow sand filter treatment system requires large volumes of wastewater and needs in this case grey water from several households to keep the bio layer from drying out. These large volumes could possibly be able to support a viable bio layer and therefore an efficient treatment. If the bio layer was to dry out, the biological cleaning would collapse and the resulting treatment would only consist of the mechanical rinsing provided by the sand, as in a fast sand filter. The first time the system is filled it will require a volume of 1 000 liters, as estimated due to the recommended volume of two cubic meters for a three-step system to sustain a wastewater treatment for a family of five. (Trekammarbrunn, 2013) The volume can be adapted to the situation, with a variation in resulting water quality depending on the design. The volumes of the containers can be varied, or one of the steps can be excluded to create a two-step system. This would give a system of slightly lower volume, but lower cleaning efficiency. As a result, the top layer of the sand filter would have to be changed more often to avoid clogging of the system.

Quantity of water losses can be predicted using the Penman equation (Shuttleworth, 2007), which describes evaporation from an open water surface. Further explanations of the components of the equation are showed in appendix 4.

Penman's equation of evaporation:

$$E_{mass} = \frac{mR_n + \rho_a c_p (\delta e) g_a}{\lambda_v (m+\gamma)} \qquad (2)$$

The equation (2) requires information such as specific temperature, wind speed, humidity and solar radiation. It is preferable to calculate when a specific placement of the system is found. The evaporation can be minimized in the design by covering all surfaces from the natural elements, and thereby protecting the water from other contaminations. (Ivarson, 2014)

If the losses of water can be estimated to around 30 percent, depending on the execution of the system, where evaporation and leakage affects the output volume, and if a flow-through-time is estimated to 24 hours, this would give a 30 percent loss of volume per day. Therefore the minimum inflow required to the system would be estimated to 300-500 liters per day or six to ten laundry loads.

7.3 Reuse of Treated Compared to Non-treated Wastewater

Grey water that is treated with this technical solution will get a reduction of particles and nutrients. The particles will be rinsed from the water in all steps of the process and the active bio layer will neutralize unwanted substances as substrate. In treated wastewater the amount of phosphate, sodium and nitrogen will be reduced. The resulting small levels of phosphate and sodium are acceptable, since they are essential nutrients to plants and will be utilized if they are added in very small amounts. As a result, the quality of the treated water is assumed to be good enough to be reused for irrigation of flowers and vegetables. As mentioned in section 4.5.1, if the vegetables are to be eaten raw, the water needs to live up to the standards presented in table 4. This will first be known after the implementation if these standards are achievable or not. It is difficult to assume treatment efficiency before the solution is executed, since a variation in design will change the results. For example, the height and sand quality in the sand filter will affect the treatment significantly. Regardless of the exact results of the system, any treatment efficiency will improve the water quality compared to not treating the wastewater at all. If tests cannot be done continuously for the water quality after treatment, the water can be used to irrigate plants with the fruits and vegetables higher up, to avoid direct contact.

The most important and interesting use of the water is to reuse it in the washing machine. This would help keeping the water consumption low, and optimize the concept of a washing machine, because the entire system would be more cost effective due to the lowered use of fresh water. This could be achieved by collecting the treated water in a different tank placed on the roof and connected to the washing machine via a hose or pipe. The water can also be reused for flushing toilets. Due to the slightly reduced levels of pathogens in the water, the risk of forming aerosols from bacteria is lower. The water can be used in general for everyday chores like washing of floors and windows, due to the reduced content of unwanted substances.

The technical solution thus gives a function that both saves water and is adequately clean for irrigation, but also good enough for reuse in the actual laundry process (Norberg, 2014). If rainwater is used in the treatment system instead of laundry wastewater, the resulting water quality might be even higher. Therefore it can be assumed that this system in another context than laundry might give water good enough for drinking.

Untreated water is not usable for the activities previously mentioned, except for irrigation. The untreated water from a washing machine will work for irrigation flowers, but not plants for eating raw. However, this is not a recommended option due to the high levels of nutrients and surfactants in the wastewater. The soil already contains vital nutrients needed for the plants to survive. If extra nutrients are added the soil can get saturated with the nutrients, which will make the soil unable to bind them and therefore the plants will not be able to utilize them. If this happens, cultivation in that soil will be more difficult. The nutrients that are not bound by the soil will end up in the oceans and stimulate over fertilization and ecological unbalance.

Normal soil contains both cat ions and anions, which are both vital for plants survival. As described in section 4.5.1, untreated water contains alkaline, which makes the pH of the soil acid. If the wastewater is added to the soil it can create an unbalance to the pH level. When the pH is too acidic, the cat ions will not bind to the soil and will therefore be washed away. As the plants need cat ions to survive, the cat ions that remain in the soil will be collected by the plants. This creates a negative spiral of progressively more acidic soil. This process will in the long run make cultivation difficult.

7.4 Drying

Tumble drying demands significant amounts of energy (Göteborg Energi) and is therefore not a viable option. Hanging the clothes to dry does not need any energy but instead requires relatively much space. A line-drying method is still deemed to be the best option in this case since energy is a high cost resource. To dry wet clothes means an evaporation of water to the atmosphere. The process of drying results in a loss of input water.

8 Implementation

In this section two ideas of implementation of the laundry concept are presented. The first idea is a business solution with opportunity to create employment and potential income. The other idea is a self-service system where the residents can do their laundry for the specific cost of usage. Both the business and self-service laundry solutions are then further analyzed in the context of implementing in an existing working cooperative as the one described in section 2. The following economic estimations are considered for a single washing machine unit but can be expanded to include further washing machines. As shown in the cost comparison in chapter 4.3, between washing by hand and washing with a machine the price for washing by hand is almost twice as expensive, which indicates that changing to a washing machine is economically beneficial. All possible solutions would gain from help regarding investments and support from non-governmental organizations, NGO, which may be needed to make the implementation feasible.

8.1 Business solution

A business solution has the potential of creating income, which could benefit the economic situation in the community. The business would set its own prices and be in charge of maintenance. A suggestion is that the business would start with one washing machine and expand if the demand for washing increases. If there is demand and another washing machine is added to the business, the expansion would not increase the use of land significantly and it is reasonable to assume that the operator can manage more than one washing machine at one time. Therefore, a larger business with more than one washing machine would produce higher profits.

However, it is reasonable to assume that the volume of laundry is fairly low in the beginning of the business. Therefore, the salary might not be satisfying for the people running the business. If financial sponsorship is received for investments of a washing machine and a treatment system, it might be possible for the business to endure the startup period, without this the organization would probably struggle. Another potentially problematic expense is the cost of land, if it needs to be purchased. Renting land with a payment plan would be financially superior during the upstart period of the business, or possible placement in the home of the operator. If there is not enough income from the washing system due to too few washing cycles per day, a solution might be if the operator could perform other work during or in between the laundry cycles. The employment in the laundry business could be seen as a part-time duty if there are not enough costumers to provide for a full-time salary.

Furthermore, in a strict business economical perspective the environmental impacts cannot be expected to be considered. This would presumably result in the water treatment method not being an economically viable option. However, if there were a possibility to get funding for a substantial part of the treatment system it would be economically favorable to incorporate the treatment system as well. The treatment system does not only reduce the water cost but also creates an option to sell or return treated water to customers or reuse in other situations.

8.1.1 Economic estimations for a business

The following chapter shows economic estimations of a business solution. Many assumptions have been made to create a rough estimate of profit fluctuation in relation to costs. The costs for the technical solution, as explained in section 5.3, includes a washing machine and water treatment system since these two products have the most impact on the economic estimations. As this is only estimations, other needed components are not considered in the investment. The results of this, and continuous predicted costs and winnings, can be used as an indicator of the possibilities to implement a business. A break-even chart is made to evaluate price-settings and potential income. Further, to analyze investment costs, the pay-back method is used, as presented below.

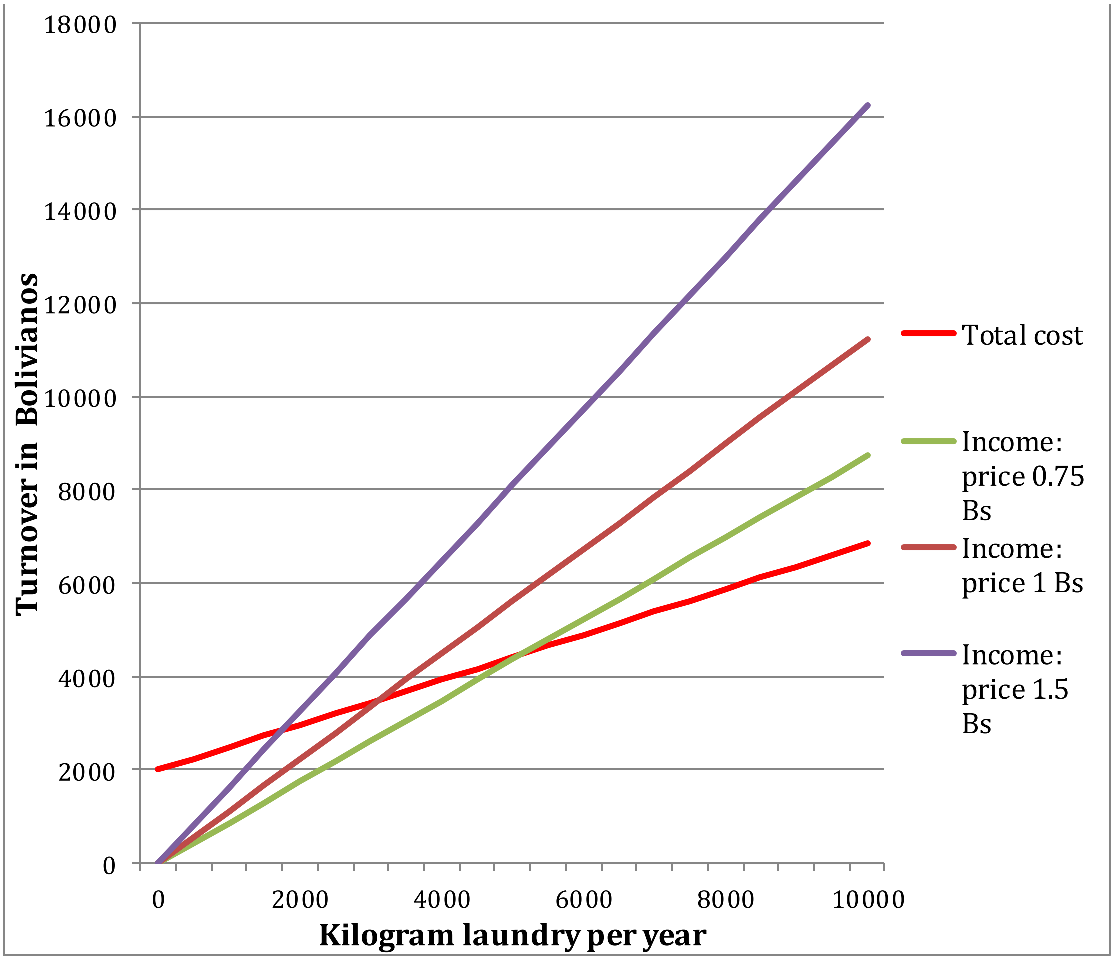

Figure 17: Break-even chart presenting total costs and total income for an economic operation with different income values depending on the price per kg laundry that is washed. Data are taken from appendix 2.

The estimations are based on values presented in section 4.5. These values are converted to the units of bolivianos per kg as shown in appendix 2. The diagram presents variable costs dependent on the amount of laundry washed per year. Fixed cost is assumed to be 2 000 Bs per year which corresponds to rent for the potential area needed. No investments costs are included in figure 17.

Figure 17 shows that if, for example, the laundry facility washes four cycles per day, 25 days per month, with a fully loaded machine each time (which equals to 9 600 kg laundry per year), the total cost would be 6 600 Bs and the total income would be around 15 600 Bs, if the price is set to 1.5 Bs per kg laundry. In this example the profit would be 9 000 Bs per year, which would cover, for example, possible salaries, land use, reparations and maintenance. The intersection of the income line and the total cost line is the break-even point, which shows where the income equals the cost and no profit is made.

If the price equals the cost of hand washing, 1 Bs, the pay-back time is 2.25 years as shown in appendix 6.

8.2 Self-service laundry solution

Self-service laundry is an opportunity for everyone in a specific area to wash for a cost without financial interests of making profit. The users pay for access to the facility and wash their own clothes. This demands some kind of organization to take care of the facility and a booking system. A group organization could be beneficial in sense of strengthening the community, but there is also risk of conflict regarding, for example, management and financing reparations. To avoid such obstacles there should be clear rules or policies for who has access to the system, for example a specific part of the neighborhood, and who manages the maintenance. This would mean maintaining the washing machine and also the treatment system, which needs little every day care.

Since there are no salary needed and no financial interest, this creates an opportunity to wash for a lower price than in the business solution. Due to the fact that the price of hand washing is almost twice as much as the price of machine washing gives that a self-service laundry system might be very beneficial. Installation of a water treatment system would increase the price, but with external funding it could be possible to keep an even lower price, because of the water savings. Regarding a self-service solution that is to be implemented in a smaller community, there will be other household tasks that require water and these could be located close to the laundry facility. This increases the reuse alternatives for the treated water and also gives more sources of grey water that could be treated in order to keep the treatment system damp. There will have to be restrictions regarding the water, which should be cleaned in the treatment system, and also how the treated water is distributed for reuse.

8.2.1 Economic estimations for a self-service laundry

A self-service laundry could be financed by the users themselves which could be done in several ways, for example, it could be done with a monthly fee or charges per separate washing cycles. Economical estimates and calculations have been done for a monthly rent.

The total price to wash in the laundry facility shall cover the investment costs as well as the costs for electricity and water needed. Investment costs include premises which are assumed to be 2 000 Bs per year, as in appendix 2, the treatment method which is set to 10 000 Bs in the calculations and the price for a washing machine, which is estimated to be 3 800 Bs as described in section 4.5.

The costs for water and energy is calculated for seven cycles per day, which gives about nine washing cycles per household per month, if there are 23 households using the service. These calculations result in approximately 60 Bs per household and. The calculations upon which the estimations are based are presented in appendix 5.

8.3 Business and self-service solution in Plan 700

Implementation of the former mentioned alternatives, business and self-service solution, into the area Plan 700 in Cochabamba, Bolivia, is suggested to be done either in existing neighborhoods, showed in figure 4, or in the working cooperative, mentioned in section 2.4.

One possibility is to implement the technical solution as a business solution placed in Plan 700, where the number of households is close to 340, which is enough to create the customer base needed to run a business. A suggestion is that one of the women in the working cooperative could be in charge of the business; it can be assumed that they are interested to work and learn due to their involvement in the cooperative. Starting a laundry business will probably need some sort of financial contribution or loan to cover needed investment costs. A non-governmental organization or an external partner with environment focus could be a possible financial support for the treatment system. PROCASHA, the non-governmental organization supporting the working cooperative, might be interested in developing this further.

The self-service solution is also possible to organize within the working cooperative. The positive aspect of starting the self-service in the cooperative is that the organization is already in place in forms of communication and regular meetings. It could also be implemented in other groups, such as one of the neighborhoods in Plan 700, if there is enough interest and dedication. As well as in a business solution, funding might be problematic in the self-service solution and it is likely that some sort of contribution will be needed.

A problem for women in the area is that they rather not leave their daily household duties, which inhibits them from working. If they would be free from one of these tasks, like washing clothes, it would be a step in the right direction regarding women's employment. Both solutions release time for the users but the business solution is preferable due to time saving mostly from drying and folding clothes. Another benefit with the business solution is that the operator of the business would be able, with a smaller portion of extra space, to have it in his/her own house or backyard. Location might be an issue in the solution of a self-service, since there is no obvious solution to placement. One option might be to build a new establishment, but this requires funding and land.

There are plans to build a community house in plan 700 that will work as a shared center for common interests. This might be a possible placement for the laundry solution if it is to be used by the residents in the area. The community house would solve the problem of space needed for implementation. Also, if the community house works as a gathering place, many people will see the laundry facility, which could create an interest in the area. Both the business and self-service solutions are possible to implement in the community house. If the entire community of Plan 700 builds the community house for usage, the scaling of volume for the laundry facility needs to be increased. Depending on the community housings design the business profit could go to the owners of the community house, as it is that the entire community that owns the business as a cooperative. Another option is that the profit would go to the sole owner who in turn then has to pay a rent to the community for using its premises.

9 Discussion

To find a viable and sustainable concept, many aspects needs to be considered. Economic and environmental elements have been analyzed in this report and are now to be further discussed. Also, social aspects are considered in the discussion, especially in the context of Cochabamba. It is important that these three aspects are intertwined to become a successful concept. During the work process assumptions have been made to make reasonable calculations and receive values to estimate the concept.

The made assumptions, like costs, water quantity losses and technical estimations, have been necessary to receive a result. A continuous challenge throughout the project has been the lack of knowledge about the site of implementation. Even if there has been cooperation with supervisors on site, a lot of information cannot be gained until a more detailed pre-assessment has been done and the system has been built and tested on site. Examples of information to gain on site are the exact cleaning efficiency of the treatment system, space needed, costs and social acceptance from the residents. The social interest could be obtained by conducting a survey of interest. If more time and resources had been available during the project, better estimations could have been made, for instance lab work that could have given a fair indicator of the water treatment efficiency.

The concept suggested is not a complete solution but rather a concept developed to be applicable in Plan 700, Cochabamba. Where the controlling factors are; scarce water resources, expensive land and access to electricity. Smaller changes may be necessary since many things are hard to evaluate without precise information. If the concept is to be implemented in other developing areas, there may be differences to the situation in Cochabamba, and alterations of the concept need to be made. The conditions that could differ and affect the implementation are the properties of the controlling factors in the developing area. For example, if energy is very expensive, heat exchanges could be considered and also solar energy as an energy source. Techniques to lower the concept's need of electricity have not been investigated in this report, but could be further studied.

One important aspect with this study was to improve the situation for the women in Plan 700; an efficient washing facility may give especially women improved prospects of everyday household work. The concept is releasing time for the women doing laundry, which is an important factor to have the chance to work or to pursue an education. A simple and cost effective way to wash clothes might also ease the accessibility to maintained hygiene. Social drawbacks from applying this concept can be a general resistance to the idea, based on lack of trust of the technology and treatment system. Also, due to the water war, water is a sensitive subject, which might cause people to have a negative attitude towards new techniques of using water. There can also be a public mistrust in the ability of the washing machines effectiveness to clean to the standard of hand washing.

The potential users of the laundry concept may need a demonstration of the technique and washing results, in order to accept the concept. Introduction of a product that consumes electricity might appear negatively to people that are economically strained. However, the fact that it is almost half the price to do laundry with washing machine compared to hand washing is considered to be a major reason to start using washing machines. The decreased usage, and therefore cost, of electricity, detergent and water is an indirect incitement for this more ecological way of washing. Release of time is further hopefully something that the residents will approve of and therefore it could also be a strong argument. To further benefit economically, it is suggested that there is a group of people using the machine, instead of single households. Younger people and people that have earlier lived in areas with higher living standards might have a more positive attitude towards washing machines than older generations, who are more used to traditional methods. If that is the case, the concept might have better chances of implementation if it is suggested to a younger target group.

The opportunity to make money could be a motive for people to start up the laundry facility as a business. Hopefully the demand for washing machines increases as the business grows and more people would start using the service on a more daily basis. When the demand is high enough new laundry facilities of different kinds can open and eventually washing machines can be subject to a broader use. The business creates at least one job opportunity and if the business gets successful, there is a chance that more people get interested in this type of entrepreneurship. This would result in that the area, Plan 700, would gain economic development. However, for women to be able to work they might need some kind of day care center, since many women have responsibility of raising children. One advantage of working in a laundry service is that in contrast to many other workplaces, you can bring your children.

A disadvantage with the business concept is the investment costs. It is hard for a single person or family to finance the premises, the washing machine and the water treatment system needed. Therefore a financial contribution might be necessary. Making one person that has economic limitations in charge of the facility also increases the risk that the treatment system will be excluded, which would have negative environmental effects and also eliminate the chance to reuse water. In a business solution, the manager can match pricing with demand, which is not as likely in a self-service facility. The fact that the prices are set to cost of usage in a self-service solution is beneficial in a social aspect since it eliminates the risk that washing in machine would be considered as an exclusive service that not everyone can afford. Since the cost of usage for washing in machine is lower than washing by hand it means that the families' economic situation is not negative affected by changing methods to machine washing. The calculation that compares hand washing to machine washing does not include the water treatment method, and it is hard to evaluate the water saving in relation to the investment cost for the treatment system. The households using a self-service solution with the treatment system will benefit due to reduced water costs, as the treatment system can be used for laundry water but also grey water from other household activities.

Treatment systems with a slow sand filter and sedimentation systems of three steps have been used in other projects in similar setups but in production of drinking water from rain water. The main focus of this project has been a laundry system with treatment of grey water to maximize the reuse possibilities. If there is not enough wastewater from washing cycles per day, the treatment system can be used as a general purification method of grey water. Since trucks deliver the water it could be a possibility that the problem of reliability and consistency of water supplies. The mentioned bad roads could for example inhibit the truck from reaching all its destinations. In general the water treatment is a good way to save water, and decrease the dependency on the rather unsecure delivery system of the water delivery trucks.

Many companies are conducting research concerning a closed system of recycling for water into the washing machine, but an answer is not found yet. The idea of a closed system with automatic backflow to the washing machine from the treatment system would give lower quantity losses and easier everyday usage for the operator. This would be a more technically complicated system that is harder to maintain for the user, because of the higher level of technology, knowledge and equipment that would be required. Further, the costs of such a system would probably be remarkably higher. The idea of a closed system with the treatment system and the washing machine is something that could have been further studied in this project if there had been more time.

From an environmental aspect the concept is beneficial because it minimizes the discharge of harmful chemicals, due to the lower amounts of detergent needed when washing in machine compared to by hand, and also because the treatment system reduces the amount of discharged chemicals. On a local level, this will give a better pH and nutrient balance in the soil, which will ease cultivation and give more pleasant surroundings. Further studies that regards the environment, is the use of alternative detergent. For instance, soap nuts and flakes, could reduce the amount of chemicals in the grey water and therefore be more environmental friendly and also demand a less extensive treatment system.

A disadvantage with the concept is that it has no risk assessment regarding what happens if a washing machine breaks earlier than expected or something happens with the treatment system. As these products are expensive to purchase, the lack of risk assessment is a weakness in the concept and the presented economic calculations. Therefore, it is important to educate the manager and users with good knowledge of maintenance and less complicated reparations. This would make the economics of the concept less vulnerable. Some of the economic estimations have been rough which can create uncertain results. For instance, cost for premises and treatment method were especially hard to estimate. The fact that some of the estimations are uncertain makes it important to consider a margin of error. However, the concept is considered to be relatively reasonable.

This concept could be a first step in introducing the washing machine to this community. Hopefully in time, it could become socially accepted and thereby making the majority converts from hand washing to machine washing.

10 Conclusion

The proposed concept contains a technical solution, including a frontloaded washing machine combined with a wastewater treatment system and also implementation of these. The treatment system is a slow sand filter that is initial connected to a sedimentation system of three steps and a filter; this makes a likely reuse to irrigation, cleaning or toilet flushing possible. Also, the treated water can be reused in the washing machine to minimize the use of water. The technical solution is suggested to be implemented either as a self-service facility or as a business idea. The concept is considered to be a sustainable laundry solution, as it is environmental friendly and improves the situation for the women in Cochabamba. However, it is yet to be seen if it is going to be successfully implemented, either in Cochabamba or in an area similar to it.

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Appendix 1: Cost estimations washing by hand and washing machine

Water cost

Cost for one liter water in plan 700 (200 liters for 5 Bs):

$$Cost\ for\ one\ liter\ water = \frac{5}{200} = \mathbf{0.025\ Bs}$$

Washing machine

Table A1.1: Compilation of several washing machines at the market.

Product	Capacity [kg]	Energy consumption [kWh/loaded machine]	Water consumption [l/loaded machine]	[l/kg]
WAS327B1SN	8	1.2	56	7
Siemens WM16S762DN	8	1.2	56	7
ElektroHelios TF 1455E Frontmatad	6	1.02	54	9
Samsung Ecobubble WF1124XAC	12	0.81	70	5.83
Gorenje WS41101	5.5	0.85	44	8
Electrolux EWPT4761FW	7	1.07	50	7.14
Samsung WF70F5E3P4WEE	7	0.56	43	6.14
Siemens WM14Q451DN	8	1.23	39	4.88

The facts about listed washing machines are collected from websites of manufacturers like Bosh, Siemens, Samsung and Electrolux and also from prisjakt.se, gransbygden.se and viivilla.se.

Mean value for water consumption [l/kg laundry]:

$$Mean\ water\ consumption = \frac{7+7+9+5.83+8+7.14+6.14+4.88}{8} = 6.87\frac{l}{kg} \approx \mathbf{7}\ \frac{\boldsymbol{l}}{\boldsymbol{kg}}$$

Mean value for capacity [kg]:

$$Mean\ capacity = \frac{8+8+6+12+5{,}5+7+7+8}{8} = 7.7\ kg \approx \mathbf{8\ kg}$$

Water consumption per loaded machine [l]:

$$Water\ consumtion = 8 \times 7 = \mathbf{56\ l}$$

Cost for one kg laundry (seven liters water per kg laundry):

$$Cost\ for\ one\ kg\ laundry = 7 \times 0.025 = \mathbf{0.175\ Bs}$$

Cost for one washing cycle (eight kg laundry per cycle):

$$Cost\ per\ cycle = 0{,}175 * 8 = \mathbf{1{,}4\ Bs}$$

Hand washing

Mean weight per set of laundry (30 items-8 kg):

$$Weight\ per\ item = \frac{8}{30} = \mathbf{0.27\ kg}$$

$$Weight\ per\ 23\ items = 27 \times 23 = \mathbf{6.1\ kg}$$

Water consumption:

$$Water\ consumption\ per\ kg\ laundry = \frac{90}{6{,}1} = \mathbf{14.8\ \frac{l}{kg}}$$

Water cost per kg laundry:

$$Water\ cost = 0{,}025 \times 14{,}8 = \mathbf{0.37\ \frac{Bs}{Kg}}$$

Purchase price for washing machine

Table A1.2: Table of different washing machines and the price.

Product	Price
Lavadora Wirlpool 8 kg frontload	3 900 Bs
Samsung EcoBubble WF0752WJW 7.5 kg frontload	4 180 Bs
Secadora 6 kgrs electrica Frigidaire 6 kg	2 450 Bs
5 kg	1 350 Bs
7 kg	3 400 Bs

The prices for the listed products are collected from websites associated with Bolivian resellers like dismac.com, tibo.bo and triplex.com.bo. The two last ones are information from Ida Helgegren collected in stores in Cochabamba.

Average price for a machine with a capacity near eight kg (7-8 kg):

$$Average\ price = \frac{3900 + 4180 + 3400}{3} = 3\ 827\ Bs \approx \mathbf{3\ 800\ Bs}$$

$$Price\ per\ cycle = \frac{3800}{5100} = \mathbf{0.75\ Bs}$$

$$Price\ per\ kg\ laundry = \frac{0.75}{8} = \mathbf{0.094\ Bs}$$

Detergent cost

Machine washing

Detergent cost for a machine with a capacity of eight kg laundry (100 g detergent per cycle):

$$Cost\ per\ cycle = \frac{15 * 100}{900} = \mathbf{1.67\ \mathit{Bs}}$$

$$Cost\ per\ kg\ laundry = \frac{1.67}{8} = \mathbf{0.21\ \mathit{Bs}}$$

Hand washing
Detergent cost for hand washing (200 g detergent per set of 5.75 kg):

$$Cost\ per\ 200\ g = \frac{15 * 200}{900} = \mathbf{3.34\ \mathit{Bs}}$$

$$Cost\ per\ kg\ laundry = \frac{3.34}{5.75} = \mathbf{0.58\ \mathit{Bs}}$$

Appendix 2: Economical estimations for business solution

Table A2.1: Data written in the table has been used in the business solution to calculate the annual cost, annual income and profit for the studied area, Plan 700. All data can be changed due to situation.

Data		
Price		
Price per kg laundry:	[Bs]	X[15]
Price (savings) per l water:	[Bs]	0.025
Work:		
Washing cycles per day:	[Numbers]	4
Workdays per month:	[Numbers]:	25
Information of the system:		
Capacity for machine:	[kg]	8
Energy consumption:	[kWh/cycle]	1
Water consumption: (l/cycle)	[l/cycle]	56
Number of cycles during life-span:		5 100
Efficiency for treatment method [%]		80
Purchase price		
Detergent (100 g):	[Bs]	1.67
Water (100 l):	[Bs]	2.5
Electricity (kWh):	[Bs]	0.8
Sum:	[Bs]	**4.97**
Assumption:		
100g detergent per cycle of washing		
Investment costs:		
Washing machine:	[Bs]	3 800
Treatment method:	[Bs]	10 000
Premises:	[Bs]	2 000
Other:	[Bs]	0
Sum:	[Bs]	**15 800**

[15] X is a variable depending on the price per kg laundry, which has been set to different values in the calculations.

Table A2.2: Overview over the annual cost in the business solution.

Annual costs [Bs]			
Variable costs:		**Total**	**Bs/kg**
Detergent:	[Bs]	2 004	0.21
Water:	[Bs]	1 680	0.18
Electricity:	[Bs]	960	0.1
Maintenance:	[Bs]	N.A	N.A
Reperation:	[Bs]	N.A	N.A
Salary:	[Bs]	N.A	N.A
Other:	[Bs]	N.A	N.A
Sum:	[Bs]	**4 644**	**0.48**
			0.48
Fixed costs (not dependent of washing volume):			
Salary:	[Bs]	N.A	N.A
Premises	[Bs]		5 000
Electricity	[Bs]	N.A	N.A
Other:	[Bs]	N.A	N.A
Sum:	[Bs]	**0**	**5 000**

Table A2.3: overview over the annual income in the business solution.

Annual income [Bs]			
		Total	**Bs/kg**
Sales / Saving of water	[Bs]	1 344	-
Laundry business	[Bs]	19 200	-
Sum:	[Bs]	**20 544**	**2.14**

Appendix 3: MCA calculation example

An example of how the calculation in the MCA has been done, the calculation for *cleaning ability* for slow sand filter follows:

The heading *cleaning ability* is graded as 1 and the parameters connected to *cleaning ability* are weight as chemicals: 3, pathogens: 1 and particles: 1. The points for the parameters are for slow sand filter chemicals: 3, pathogens: 2 and particles: 4.

First, the specific parameter score is multiplied with the weight for that parameter. In this case: $3 \cdot 3$, $1 \cdot 2$ and $1 \cdot 4$, these are then summarized. The score for c*leaning ability*, for slow sand filter is thereby 15. This is then made for the other two consecutively in the same way, 20 and 25. The total score is then a summation of the different scores from each topic multiplied with each topics weighing: 1, 1 and 2.

This gives a total score of: $15 \cdot 1 + 20 \cdot 1 + 25 \cdot 2 = \mathbf{85}$

Appendix 4: Penman´s equation of evaporation

$$E_{mass} = \frac{mR_n + \rho_a c_p (\delta e) g_a}{\lambda_v (m + \gamma)}$$

m is the slope of the saturation vapor pressure curve.
R_n is the net irradiance.
ρ_a is the density of air.
c_p is the heat capacity of air.
g_a is the momentum surface aerodynamic conductance.
δe is the vapor pressure deficit, λ_v is the latent heat of vaporization.
γ is the psychometric constant.

The equation is used with SI units, and gives the evaporation in the unit: $\frac{kg}{m^2 s}$.

Temperature, humidity and wind speed has a great impact on the values of m, g, c_p, ρ, and δ. (Shuttleworth, 2007)

Appendix 5: Pay-back method in business solution

Table A5.1: This table shows the pay-back time for a business solution

Payback method		
Income:	[Bs]	10 776
Expenses:	[Bs]	4 644
Investment cost (G): (Treatment method+washing machine)	[Bs]	13 800
Annual turnover excess (a):	[Bs]	6 132
Payback time in years: (T) =G/a	**[Years]**	**2.25**

A rough estimation of how long the payback time would be not considering interest rate.

Table A5.2: Shows numbers to use for calculation of the life length of the washing machine.

Life expectancy washing machine		
Number of cycles during life-span:		5 100
Washing cylces per day:	[Cycles per day]	4
Workdays:	[Per month]	25

Equation of the life length of the washing machine, dependent at number of cycles during life-span:

$$\boldsymbol{Life\ lenght} = \frac{5\ 100}{4 \times 25 \times 12} = \boldsymbol{4.25\ years}$$

Appendix 6: Approximate monthly pay for self-service laundry

Table A6: Data from income and expenses for a self-service implementation.

Calculations for cost per month		
Investment cost		
Washing machine:	[Bs]	3 800
Treatment method:	[Bs]	10 000
Premises:	[Bs]	2 000
Sum:	[Bs]	**15 800**
Numbers of cycles during life-span:		5 100
	[Cycles per day]	7
	[Days per month]	30
	[Months per year]	12
	[Cycles per year]	2 520
Life span:	[Years]	2.02
	[Bs per year]	7 807.06
	[Months per year]	12
Monthly cost for investment:		**650.59**
Monthly costs		
Water:	[Bs per l]	0.025
	[l per washing cycle]	56
	[Cycles per day]	7
	[Days per month]	30
	[Bs per month]	**294**
Electricity:	Bs per kWh	0,8
	[kWh per cycle]	1
	[Cycles per day]	7
	[Days per month]	30
	[Bs per month]	**168**
Premises:	[Bs per year]	2 000
	[Bs per month]	**166.67**
Sum monthly costs:	[Bs per month]	**1 279.26**
Houses in Plan 700		340
Neighborhoods in plan 700		15
Houses per neighborhood		22,67
Cost per month per houshold	(Sum monthly costs/ Houses per neighborhood)	56.44
Approximate cost per household per month		**60 Bs**
Number of washes per household and month (30*7)/22,67		≈ **9**
⇨ **60 Bs per household to wash approximately 9 times a month.**		