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Cochabamba

- Sustainable water management in suburban communities

Bachelor Thesis BMTX01-12-73

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Abstract

Fresh water is essential for all life on earth and is therefore one of the most important natural resources. Many places worldwide lack access to proper water and sanitation systems, which also is the case for the poorest country in South America: Bolivia. One of the largest cities in Bolivia is Cochabamba, a city affected by water conflicts such as the Water war in 2000 that ended with the death of a 17-year old boy.

Cochabamba is in great need of improved water supply systems, especially in the outskirts where there are practically no municipal influences, which makes water costly and inaccessible. Low-income people are mostly populated in the outskirts why the situation becomes severe due to the strains of obtaining enough water. One way of solving the water problems outside Cochabamba, still considering financial restrains, is by the housing cooperative model. A benefit with cooperatives is the possibility of being granted bank loans, which makes development of a cooperative with satisfying water and sanitation system feasible.

The aim of the thesis is to develop and present a framework, which describes a process on how to plan a water and sanitation system for a cooperative household. Central aspects in the development of a functioning system are availability, sustainability and economy, which all together form a foundation for the whole system to rely on. The process is purposed to develop a solution satisfying these visions through appropriate water resources, accurate treatment if needed, reliable distribution and careful handling of sanitation. A selection of technical solutions is intended to be subject for further evaluation through a multi criteria analysis. It is crucial that all these are developed interactively with local conditions, possibilities and limitations.

The study results in a *Water solutions scheme for cooperative households*, showing that a future water and sanitation system in Cochabamba should include a drilled well connected to a piped distribution network. After household consumption, the water is stored in a septic tank where solids are separated from liquids. Solid waste is later transported with de-sludger and treated at a sludge treatment plant while liquid waste is handled in a subsurface constructed wetland.

The scheme is also applicable in similar situations worldwide to solve water problems.

Key words: Cochabamba, water, cooperative, water extraction, sanitation, water treatment, distribution, developing countries

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Sammanfattning

Sötvatten är en förutsättning för allt liv på jorden och är därför en av de viktigaste naturresurserna. Många ställen i världen saknar tillgång till fungerande vatten- och avloppssystem vilket också är fallet för det fattigaste landet i Sydamerika: Bolivia. En av de största städerna i Bolivia är Cochabamba, en stad som drabbats av vattenkonflikter såsom vattenkriget 2000 vilket slutade med att en 17-årig pojke avled.

Cochabamba är i stort behov av förbättrade vattenförsörjningssystem, särskilt i utkanten av staden dit kommunala system inte når vilket gör vattnet dyrt och svårtillgängligt. De flesta som bor i utkanterna är låginkomsttagare vilket försvårar vattensituationen ytterligare. Ett sätt att lösa vattenproblemen utanför Cochabamba, med hänsyn tagen till finansiella restriktioner, är att gå samman och skapa kooperativ. En fördel med kooperativ är möjligheten att beviljas banklån vilket i sin tur gör utvecklingen av ett kooperativ med väl fungerande vatten- och avloppssystem genomförbar.

Syftet med avhandlingen är att utveckla och presentera ett ramverk som beskriver hur ett vatten- och avloppssystem kan projekteras för hushållskooperativ. Centrala aspekter är tillgänglighet, hållbarhet och ekonomi som tillsammans utgör grunden för ett fungerande system. Processen ämnar utveckla en lösning som uppfyller dessa faktorer genom lämpliga vattenresurser, korrekt behandling vid behov, tillförlitlig distribution och noggrann hantering av avloppsvatten. Ett urval av tekniska lösningar kommer vidare utvärderas i en multikriterieanalys. Stor vikt läggs vid att dessa utvecklas i samverkan med lokala förhållanden, möjligheter och begränsningar.

Studien resulterar i en *vattenplan för hushållskooperativ* som visar att ett framtida vatten- och avloppssystem i Cochabamba bör bestå av en borrad brunn ansluten till ett vattenledningsnät. Efter hushållens konsumtion lagras vattnet i en septiktank där fast och flytande material separeras. Fast avfall transporteras sedan via en slamsugningstank för vidare behandling i ett reningsverk medan flytande avfall hanteras i en konstruerad våtmark.

Vattenplanen kan även tillämpas i liknande situationer världen över för att lösa vattenproblem.

Nyckelord: Cochabamba, vatten, kooperativ, vattenutvinning, avlopp, vattenrening, distribution, utvecklingsländer

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Preface

This report has been developed for the division of Water and Environment Technology at Chalmers University of Technology. The report intends to contribute to an on-going project in Cochabamba which our supervisor Sebastien Rauch is involved in. We would like to thank Sebastien for all knowledge and guidance he has provided throughout the process.

1 Introduction

"The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses. An adequate amount of safe water is necessary to prevent death from dehydration, to reduce the risk of water-related disease and to provide for consumption, cooking, personal and domestic hygienic requirements." (UN, 2012)

Water is recognized as a human right, which is why water should be available for everyone. Fresh water is essential for all life on earth and is therefore one of the most important natural resources. The geographical situation often regulates the accessibility of water while treatment controls the quality, i.e. what the water is suitable for. Therefore future life on the planet demands access to water of the right quality.

However, there are a lot of places on earth that does not fulfill these requirements; this consequently has a negative impact on the overall health of humans and nature. Water treatment, e.g. bad sanitation, is one of the major problems. More than 2 billion people do not have access to proper sanitation and annually 1.5 million children die from diseases related to it. (UNICEF/WHO, 2008) The supply of natural water is highly dependent on the amount of precipitation, due to absence of rainfall it is approximated that nine hundred millions of people lack adequate access to water. (Brocklehurst, 2010) Under these circumstances, the risk of civil disorder, spreading of diseases or insufficient harvest is much more likely to occur. Accordingly, a society without adequate water resources will have severe impact on all life within. (Carius, 2004) Many developing countries struggle with issues of water and sanitation.

In Bolivia, the poorest country in South America, scarce water resources have been a severe problem for a long time, leaving the population notably affected. Poverty is more concentrated in the suburbs of cities; hence this is where development of water and sanitation systems is particularly challenging. In the outskirts of the Bolivian city Cochabamba, the fundamental issue is to provide the population with a working fresh water supply system. The few existing systems are in general very weak and need great improvements to effectively use the natural water resources. The most beneficial water resource (i.e. subterranean, surface or rainwater) is likely to vary with location, requiring development of several different technical solutions. Another common problem in the Cochabamba suburbs is waste water management. Without proper waste water treatment, there will be serious effects on both human health and environment.

At present, most suburbs are not covered by the municipal water distribution network. The responsibility for providing water relies on the citizens themselves to a high degree. As a direct result, small communities have emerged where people have started to collaborate and share the water supply. During the past years, so called *housing cooperatives through mutual aid* have been a pilot project in improving the possibilities for these people. This solution allows the low-income population to establish a proper water distribution network, since they are granted bank loans as a cooperative.

Despite the importance of fresh water, many people lack access to it. There is an obvious correlation between poverty and scarcity of fresh water, making this a major problem in most developing countries. Hence, the problem is not exclusively the existence of water resources, but to develop a system that is economically feasible.

2 Objectives

"If you don't know where you are going, you will probably end up somewhere else."
(Laurence, 1969)

The project procedure and framework is specified in this section. It summarizes with an illustrative figure on how the aim is going to be reached.

2.1 Aims

The report aims to evaluate and combine technical water and sanitation systems in hypothetical new-built housing cooperatives in suburban areas of Cochabamba, Bolivia. The report intends to assemble existing technologies into a complete solution with regard given to current conditions of demography, economy and available water resources. The most appropriate solution will be presented based on the conditions in different concerned communities. Results and conclusions are intended to contribute to a related ongoing research project.

The final aim is to develop a framework for choosing water and sanitation solutions based on local resources, social constraints and housing situation. The framework will be presented as a **Water solution scheme for cooperative households**, which also can be used when planning cooperatives worldwide.

2.2 Limitations

The study will focus on smaller communities in the outskirts of Cochabamba and not the urban nucleus where the situation is not as critical. Only new-built housing cooperatives purposed for lower middle-class people will be taken into consideration. The report will only focus on how to distribute water from the source to the recipient via households without presenting the interior water installations within the households. A precise budget of what a new system might cost will not be declared, however, estimations will be done by looking at similar investigations.

2.3 Method

Information and facts in this report were collected through literary studies, mainly by using online sources such as scholarly journals, reports, literature and websites provided by governmental and non-governmental organizations.

The literary study was initiated by an investigation of the present water and sanitation system in the outskirts of Cochabamba. To form a basis for the development of a sustainable technical water and sanitation solution, a list of criteria was introduced. These criteria were developed with consideration to local parameters and requirements specified by UN Human Rights. Throughout this report sustainability has been a fundamental factor; hence the criteria originate from this parameter to a large extent. Various water systems were selected to be evaluated and compared with regard given to demographic and economic conditions as well as available water resources. The report ends with a discussion and conclusions on the most appropriate solution for Cochabamba suburbs and other locations worldwide with similar needs and conditions.

To structure the evaluation of different water systems in various locations, a multi criteria analysis[1] worked as a tool to reach a conclusion.

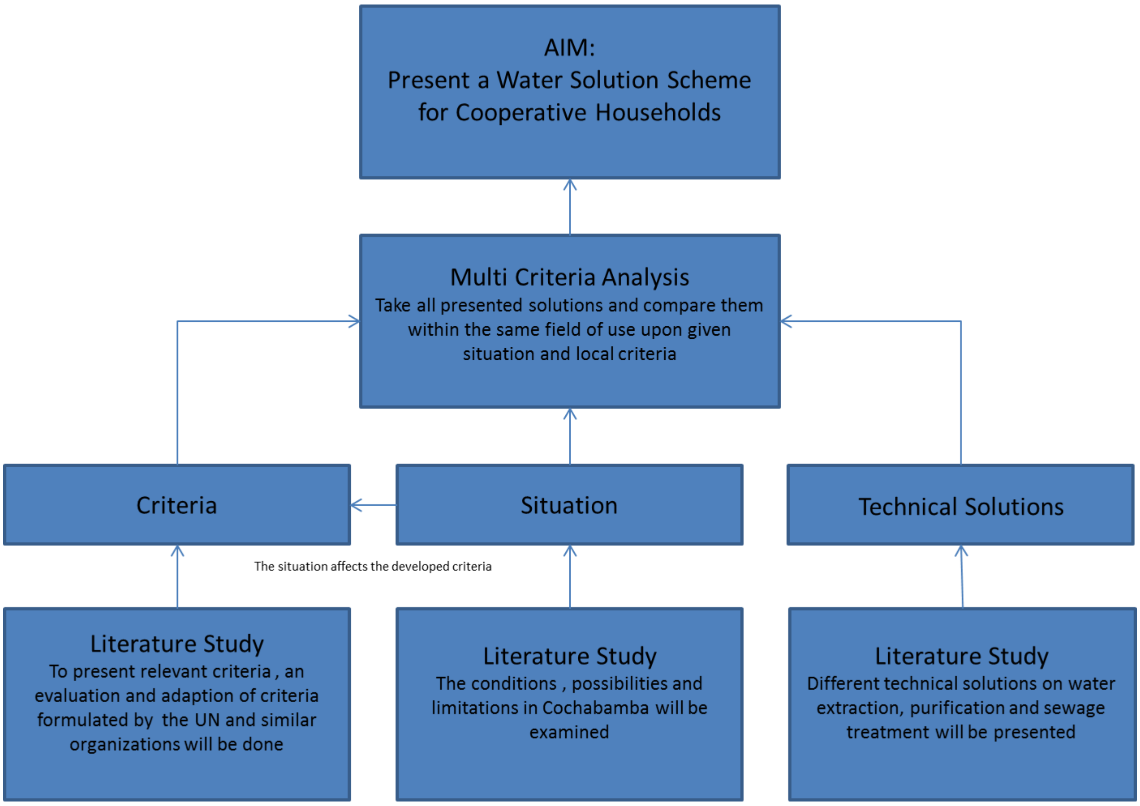

Figure 1 Schematic outline of the project workflow

[1] A multi criteria analysis (MCA) is a method for ranking different options based on a number of criteria. (Communities, 2009)

3 Cochabamba

"...city of eternal spring" (Encyclopedia of the Nations, 2012)

Bolivia is a sparsely populated country situated between the Andes and the Amazon in South America. Less than 1.3 percent of the country area consists of water and the country is completely separated from the ocean. Neighboring countries are Chile, Peru, Paraguay, Brazil and Argentina. (Landguiden, 2012) Bolivia can be divided into three geographical zones; the high plateau (The Andes and Altiplano) to the west, the semi-tropical jungles and temperate valleys and the tropical lowlands in the east. Cochabamba is located in a temperate valley which is a green and fertile region. (Boliviabella, 2012)

Figure 2 Map over Bolivia and Cochabamba (BBC, 2010)

3.1 Climate

The climate in Cochabamba is very mild and is considered to be the most pleasant climate in the country with sunny days and cool evenings. Rain season occurs during the summer months; December to March when the average temperature is 26 degrees. Dry season occurs during the winter period between June and August. The average temperature during this time of the year is around 17 degrees. (Boliviabella, 2012) Average rainfall during January to March varies between 59 and 96 mm per month (January has the highest precipitation) compared to winter season where the average precipitation varies between 3 and 7 mm per month. (World Weather Online, 2012)

3.2 Demography

Cochabamba, as well as the rest of Bolivia, is known for its great ethnic and cultural diversity. The city is populated by Quechua, Mestizo, Aymara, European descents and other indigenous ethnicities. (Boliviafacts, 2012)

3.2.1 Urbanization

During the last half century, Cochabamba has experienced a massive population growth due to urbanization. In 1950 the city population was 81,000, and the urban growth started to get seriously high. The pace of urban population growth has since then varied between approximately 3.5 and 4.5 percent annually. In 1976 the population had reached over 200,000 residents (Countrystudies, 2012) and in 2010 the city population was estimated to 618,000, which is the most up-to-date census. This is a number which, according to the trend, can be expected to continue increasing. (Citypopulation, 2012) Combined with the surrounding urban area in the region the population is estimated to reach 1 million. (World Gazetter, 2012)

3.2.2 Public health

In general, public health depends on several factors, but a main factor is the access to fresh water. In the center of the city people have access to fresh water due to higher economic standards unlike in the outskirts where people lack it. This can be related to life expectancy and children mortality where the central parts have a life expectancy about 78 years and an infant mortality about 4 percent. These are numbers which in the outskirts are respectively 54 years and 16 percent. (Ledo, 2007)

3.3 Economy

An overwhelmingly high percentage of the habitants of Cochabamba suffer from severe poverty. Poverty is unequally distributed among the inhabitants where suburban population, ethnic minorities and women are overrepresented. The poverty situation in Cochabamba characterizes the situation in several other cities located in the central parts of the country, and it is in many cases presumed to be a result of the high rate of urbanization in this area. (UNICEF, Bolivia: Situation of poverty in the country, 2003)

The big difference in the economic situation between the center and the outskirts of the city is illustrated in Figure 3. (Ledo, 2007) The image illustrates the distribution of human development index (HDI) and poverty, which are two ways of presenting standard of living. The red parts represent areas where the economic standards are lowest.

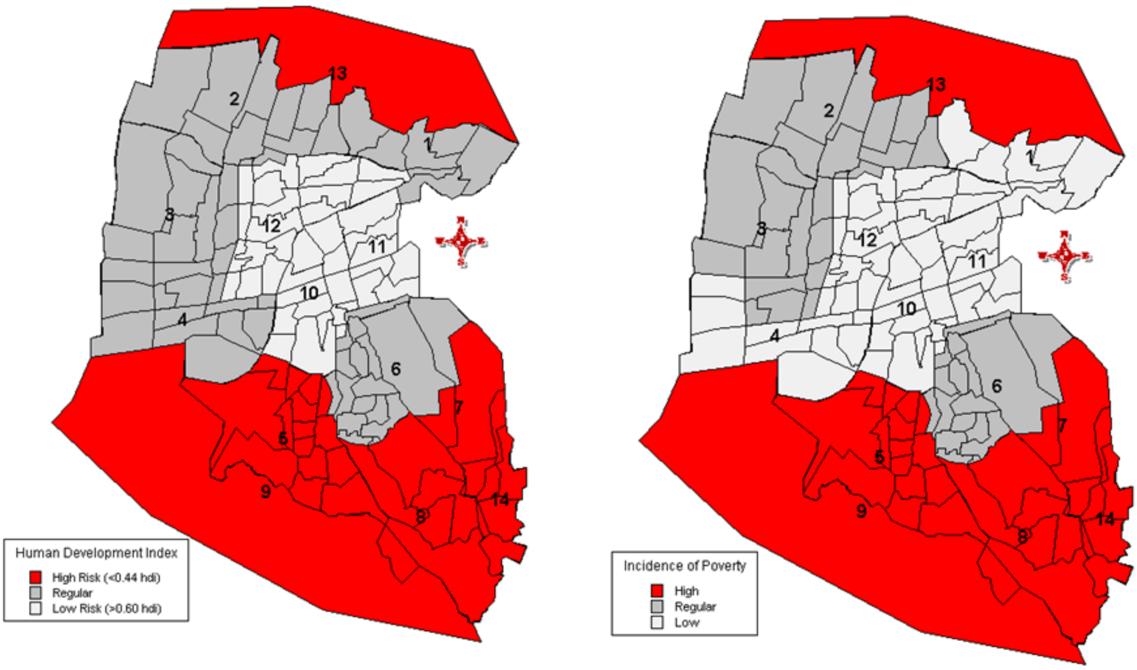

Figure 3 Districts of Cochabamba (Ledo, 2007)

4 Water resources

"Water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change." (IPCC, 2008)

Water is the most important resource of life and a human right, but far from everyone have access to proper water resources. Bolivians have access to fresh water due to the mountains and the Amazon, but many regions like Cochabamba still lacks clean water. Because of poor infrastructure, only one percent of the subterranean water sources is being used. (Peredo Beltràn, 2004) Many cities depend on several different water resources and Figure 4 shows how water resources worldwide are connected to each other in the hydrological cycle. Climate change is predicted to affect most of the processes in Figure 4 and should be taken into account when evaluating future water resources in both Cochabamba and other parts of the world. (EPA, 2011)

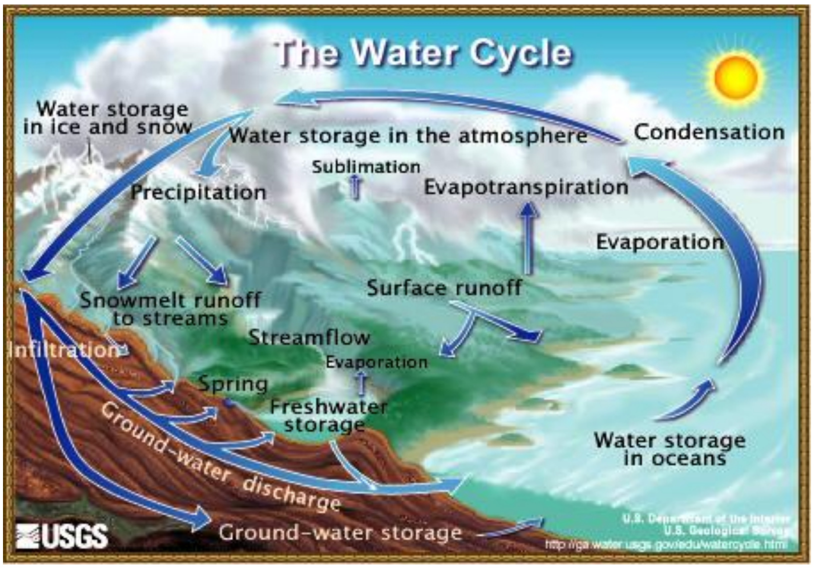

Figure 4 The water cycle, EPA/Climate Change (EPA, 2011)

4.1 Ground water

Ground water is in general of good quality due to water infiltration through soil layers. The composition of ground water is determined by precipitation, evaporation, geology and the time for which water is in contact with the soil material. Even if the soil layers works very good as a natural filter, local contaminations can still affect the quality in terms of bacteria and viruses. (Lidström, 2010)

4.1.1 Ground water in Cochabamba

The main water source in the Cochabamba valley is the aquifers[2] which store enormous amounts of ground water. There are thousands of wells in the area, many drilled to a depth of about 125 meters, which is considered relatively deep and therefore requires a

[2] Aquifer - *"A water-bearing layer of rock, or of unconsolidated sediments, that will yield water in a usable quantity to a well or spring."* (NC Water, 2010)

high amount of energy to be pumped up to surface level. (Palm, 2010) There are some major problems when drilling wells: first of all, it is not restricted and private drilling is heavily increasing. Secondly, extraction decreases the ground water level which in turn makes it more difficult to find aquifers at shallow depth, resulting in higher costs of pumping. Overall, ground water is the most suitable water resource in Cochabamba area according on Palm's case study. Surface water infiltration from mountains recharges the aquifers and contaminates water at shallow depth making it unsuitable for drinking. (Palm, 2010)

4.1.2 Climate change and ground water

Ground water flows are heavily dependent on precipitation, which is subject for fluctuations due to climate change. Aquifers all over the world have over the past decades indicated a decrease in ground water level, but not all of them are related to climate change. The recharge process is very slow in ground water systems; the lack of data and limited observations makes it difficult to make presumptions about future events.

Thawing of permafrost at higher latitudes causes changes in both ground water quality and level due to coupling with surface water. Since many aquifers are recharged by surface water impacts on surface water flows will affect the quality of ground water. Increase of precipitation can also decrease ground water recharge, where infiltration capacity of the top soil layer often exceeds with heavy precipitation, making this layer an impermeable cover. In other areas e.g. semi-arid and arid, increasing of precipitation could instead lead to an increase of ground water recharge since heavy intense rainfall is the only way for water to infiltrate fast enough before evaporation. In many aquifers around the world, recharge occurs more often during winter while summer recharge is decreasing, all as a result of climate change. (IPCC, 2008)

4.2 Surface water

Surface water, e.g. lakes and rivers, are often characterized by four factors; color, humus, turbidity[3] and bacteria. These factors cause both taste and smell, making surface water necessitate purification before being distributed as drinking water. Surface water is composed by the same factors as ground water. The quality of surface water differs depending on the resource, the quality in lakes is often better than in rivers because the water velocity is lower in lakes. This makes it easier for larger particles to sediment. On the other hand, the low velocity makes bacterial growth and viruses more commonly existent in lakes.

A few examples of contamination threats of surface water:

- Bacteria and virus from manure application, manure piles and waste water
- The possibility that a fuel truck overturns
- Increased salinity (Lidström, 2010)

[3] *"Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates."* (Lenntech, 2012)

At present in small and poor communities, particularly in dry areas, water supply relies on smaller ponds or dams. In many cases these ponds are the only source of water at a certain area, hence they are not only used for fresh water supply, but also fishing, washing and bathing. As they are situated in hollows, they also work as natural recipients for drainage water from surrounding areas. At a densely populated area with scarce water resources, there is an obvious risk for over-exploitation and excessive usage of these ponds, resulting in polluted waters and spreading of diseases. Pathogenic bacteria, viruses and parasites are commonly existent in such ponds, making the water a severe health risk instead of a resource. This kind of ponds are usually not a sustainable water source, they are rather used in absence of a proper and sustainable source. Therefore, these ponds should be carefully reviewed in aspects of health and sustainability before being used as fresh water sources. (Smet & van Wijk, 2002)

4.2.1 Surface water in Cochabamba

The river Rio Rocha flows through Cochabamba Valley and is heavily polluted by industrial waste water and poultry farms along the river. Since the water is contaminated it is only used for irrigation. The current water management company, SEMAPA, is using surface water for water supply. Two sources already in use are Escalerani and Wara Wara, providing approximately 40 percent of Cochabamba's fresh water. (Palm, 2010)

The Misicuni River is located in the mountains, at 4000 meters altitude and 33 kilometers north of Cochabamba. For a long time the river has been seen as a potential subject for water supply and electricity for the city. The river flows through a valley in a massif, making the river separated from the city, which complicates the project and brings up the costs. The water has to be transported through a tunnel in the mountains in order to reach the city. (Lindberg & Borggrén-Franck, 2012)

4.2.2 Climate change and surface water

Over the past decades there has been an observed climate-related warming of lakes and rivers. This has resulted in changes of species composition, organism abundance and productivity in fresh water ecosystems. Extended stratification with decreases in surface layer nutrient concentration and further depletion of oxygen in deeper layers are other consequences of global warming.

Increasing water temperature, precipitation intensity and periods of low flow are projected to exacerbate many forms of water pollution including e.g. pathogens and pesticides. This is favorable for algal blooms as well as increased bacterial and fungal content. Ecosystems and human health will be affected by this. The quality in lakes will also be affected by higher temperatures through increased thermal stability and changed mixing patterns, which will result in lower oxygen levels and an increased release of phosphor from sediments. (IPCC, 2008)

4.3 Precipitation

Rainwater constitutes a simple and relatively good water source without requiring any further work or financial means in order to obtain it. Untreated rainwater is generally within WHO drinking water standards and additional treatment is usually not needed.

Even at locations where rain is commonly existent, this source should primarily be used as a complementary source due to its lack in reliability. (IRCSA, 2012)

4.3.1 Climate change and precipitation

Annual precipitation is increasing and areas with a precipitation increase exceeding 20 percent occur mostly in areas at higher latitude including eastern Africa, northern part of central Asia and equatorial Pacific Ocean. There are though decreases in precipitation in some areas, e.g. Mediterranean and Caribbean regions. In general precipitation increase over land is five percent and over oceans four percent. It is likely that heavy precipitation events will be more common. Extreme precipitation increases more than mean precipitation in most tropical and mid- and high-latitude areas. Precipitation is predicted to be more concentrated in intense and extreme events with lower precipitation and longer periods between these extreme events. An aspect concerning mean precipitation is that areas with wet extremes (precipitation increase) are being more extreme and areas with dry extremes are being more severe (precipitation decrease). Increased intensity and variability with precipitation will result in increased floods and droughts which in turn affects water availability. Precipitation is projected to increase which would result in deterioration of water quality because of the improved transport for pathogens and other dissolved pollutants to the surface water and ground water. (IPCC, 2008)

5 Water management in Cochabamba

"I live in the South of Alto Cochabamba. In my zone people didn't have water. From 3 or 4 o'clock in the morning on, we had to be standing ready to buy water, since this was the hour that the water truck arrived. If you got their late, you didn't buy water….Before, each barrel of water cost 4Bs (approximately 70 cents per day) and for many people, this was barely enough to get through the day." (Peredo Beltràn, 2004)

In the beginning of the 1990s, the government conducted a legal reform which made privatization of many public services possible. Water was one of the most controversial topics for this purpose. The Bolivian government started to put their enterprises out for bidding in 1992. (Peredo Beltràn, 2004) They sold out the air line, electricity utility and several hotels around the country. (Asheshov, 1993) In the early 1999 the government received a bid regarding water rights from the private company Aguas del Tunari (AdT), which was directly declined by the government since the requirements was not satisfied. A few months later the government changed their attitude and eventually sold the water rights in Cochabamba to AdT, funded by the World Bank. This piece of business was strongly criticized by civilians and outside organizations; there were no further bidding before the final agreement and the previous bid from AdT, which was earlier declined, was later accepted with a few modifications. The agreed contract was later known for containing several serious defects, which eventually afflicted the civilians with excessive water tariffs. (Peredo Beltràn, 2004) This deficient contract was clearly not the best solution for Cochabamba's situation and contributed to a dubious approach among civilians towards new developers from other countries, resulting in the *Water War*. (Lobina, 2000)

5.1 Water War

Shortly after signing the contract, the water prices started to increase at a highly unreasonable rate. The prices culminated around the millennium shift, resulting in a 200 percent total increase since the agreement was signed according to the Bolivian government. Aguas del Tunari on the other hand, claimed that the increase was only 35 percent. (Peredo Beltràn, 2004) Speculators argue that the increase of water prices was aimed to finance a project concerning water supply for Cochabamba from the Misicuni River. (Lobina, 2000) As a direct result, civilians from different parts of Cochabamba gathered to manifest. The protests instantly grew stronger and the conflict's starting signal was when the civilians executed a road block on the main highway in Bolivia. The protest from civilians were massive and a vast majority demanded reform according to a survey among almost 50 000 people. Despite this, the government refused to oppose AdT and their water management, which contributed to even more frustration among the people. The following period of time was subject to riots, protests and violence, which escalated in April 2000 causing one casualty and several injuries. The death of a 17 year-old boy made the government realize that the situation had gone too far and began to withdraw the military forces. Shortly after, the government demanded a rescission of the contract with AdT and SEMAPA was given the job to maintain a sustainable water management and sewage system. (Peredo Beltràn, 2004)

5.2 Present water management

Progressive migrations from the countryside to the outskirts of Cochabamba in the past decades have resulted in an increasing water demand. The city of Cochabamba presently relies on a public water distribution system supplying less than half of the population, mainly located in urban areas and thereto on an irregular basis. (UN Habitat, 2012)

5.2.1 Water Governance

The institution responsible for water and sanitation in Bolivia is The Ministry of Water and includes three vice-ministries which are Watersheds & Hydro-geological Resources, Basic Service and Irrigation. (People, 2006) Several officials in these vice-ministries have backgrounds from the demonstrations regarding privatization of water in 2000. Water is now a higher priority which is reflected in the National Development Plan (NDP) with high ambitions for future water management. The government thinks that water supply should be owned and controlled by the state and public service providers rather than private enterprises because of the governments' belief in water as a human right and not a profitable business. (GU, 2007) Water supply is today managed by SEMAPA, which is highly influenced by the government and municipality. (Palm, 2010)

5.2.2 Water consumption

The economy regarding water has become a good indicator of showing how the cities' resources are divided. About 50 percent of the urban population is connected to public water systems. In the north-east of Cochabamba most families are connected to water systems and the water cost is 0.5 USD per m^3. In these parts a family is using an average of 30 m^3 $month^{-1}$ to a price of 2 percent of the family income. In the south which is the poorer part of the city without water supply connection, the water costs 5 USD per m^3 and a family is using 2 m^3 per month to a price of 10 percent of the family income. A low-income person uses approximately 0.02 m^3 (20 liters) of water per day while the average human need is estimated to be 0.05 m^3 (50 liters) of water per day. (Ledo, 2007)

5.2.3 Distribution

In order for the suburban and rural population to have water network connection, they have to either appeal to private companies or water cooperatives. At the present situation in the Cochabamba suburbs, drinking water distribution relies at a high degree on delivery by trucks. This is a common solution mainly in the southern periphery, i.e. the suburban areas south of the city center. Obviously this is not a sustainable way of dealing with the inadequate access to clean drinking water in the area. The water prices get high and the affordability decreases among the habitants. The environmental load is high, besides, delivery failures have devastating consequences. (Palm, 2010)

5.2.4 Waste water

The project *Alba Rancho WWTP* is a waste water treatment plant operated by SEMAPA. The treated water from Alba Rancho is considered important in aspects of agriculture, i.e. irrigation in areas outside Cochabamba city. (Zabalaga, Amy, & von Münch, 2007) The most common way to take care of waste water in rural areas outside Cochabamba is by a seepage pit. The seepage pit infiltrates the waste water through a hole in the ground, which is a cheap and simple method. But at poor conditions, ground water may be polluted if the maintenance is not handled correctly. A seepage pit should not be located close to a source of drinking water, with a minimum of 50 meters. (Palm, 2010)

As water resources are scarce, especially during dry seasons, significant areas in and around Cochabamba depend on treated and untreated waste water for agricultural irrigation. Due to its constant availability, farmers consider waste water as the most reliable source of water despite the inferior quality. Rainwater and surface water flow along with emission of diluted sewage containing high concentrations of heavy metals, pathogens and salts results in soil degradation. Both vegetable and fodder crops become irrigated with polluted water, forcing farmers to partially replace vegetable crops with more salt-tolerant fodder crops. Farmers in these areas do not complain about specific health problems related to the use of polluted water, yet 80 percent has skin mycosis[4] since many of them do not wear rubber boots and gloves during irrigation. (Huibers, 2004)

[4] Skin mycosis is an inflammatory disease that affects the skin. The disease is caused by fungus. http://www.livestrong.com/article/159612-common-skin-problems-caused-by-mycosis/

6 Cooperative households

"*A cooperative is an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly-owned and democratically-controlled enterprise*." (ICA, 2010)

Many people in developing countries lack financial means to build their own houses. At sites with scarce water resources and where municipal water supply is absent, it is usually also difficult and expensive to establish a separate water supply system. An emerging solution of this issue is that families assemble into housing cooperatives in which they share water supply and lower building costs. The concept of cooperative households is a way of financing and providing high-quality drinking water among low-income people. Families come together to gain economic advantages such as being granted bank loans for financing the building project. The cooperative is a non-profit organization, owned by its members with a common goal to optimize their living situation. This framework makes the members responsible for building and maintenance of their households.

Housing cooperatives in general has the following characteristics:

i. *"A housing cooperative involves itself in collective ownership of houses together with common facilities and service*
ii. *It is an organization for collecting capital, building houses and encouraging members to save*
iii. *It acquires immovable property consisting of houses, roads, drains, water supply equipment*
iv. *It provides common facilities and allied services"*

The establishment of a cooperative household results in lots of benefits. The most significant advantages concerning water management are:

- **Defined problem** - Limited numbers of households makes it easier to calculate installations and the water needed
- **Cost efficiency** - There is a major cost reduction when buying material in a larger scale which contributes to financial benefits
- **Commitment** - When the residents participate in the building process they will care more for the result. They will also care more for their house when living in it
- **Knowledge** - Residents will have a better understanding of their houses and will therefore have knowledge to maintain the systems in the future (Sedhain, 2005)

6.1 Housing cooperative organizations

In most cases housing cooperatives are supervised by non-governmental organizations (NGO). A common working method is to "help to self-help", meaning that the organization provide resources (e.g. building material, tools and knowledge) which allow the people to build their own community. (KUG, 2012)

6.1.1 The International Cooperative Alliance

The International Cooperative Alliance (ICA) is the largest non-governmental organization worldwide with 267 member organizations from 96 different countries. ICA promotes the awareness of cooperatives and enables their development. They also have a development program which provides technical assistance to cooperatives. ICA has formulated seven principle guidelines for cooperatives, which put their value into practice.

1. **Voluntary and open membership**
   The cooperatives are voluntary and open to everyone without any discrimination of its members
2. **Democratic member control**
   The members control and decide which rules to follow in the cooperative, both men and women can be elected as representatives and each member has one vote
3. **Member economic participation**
   Members contribute to the capital of the cooperative which is later used for improvements. The capital is mostly common property but sometimes people get compensation for their houses
4. **Autonomy and independence**
   Cooperatives are controlled by its members and they are autonomous. If agreements are being made with governmental or non-governmental organizations, the cooperative ensures a democratic control by its members
5. **Education, training and information**
   Education and training are provided by the cooperative in order to maintain development among its members
6. **Cooperation among cooperatives**
   By working together after mutual structures, the cooperative works most efficiently
7. **Concern for community**
   Policies decided by the members will contribute to a sustainable development of the community (ICA, 2007)

A relevant factor, in many cases the major problem, in the development of housing cooperatives is the financing and organizing of the projects. Most projects rely on assistance from non-profit organizations to handle these issues.

6.1.2 Federacíon Uruguay de Cooperativas de Viviendas por Ayuda Mutua

Federacíon Uruguay de Cooperativas de Viviendas por Ayuda Mutua (FUCVAM) is a project that has been active since the 1970's, which establishes housing cooperatives around Uruguay. The project includes 16,000 families divided into 300 different cooperatives, which results in an average of 50 families within each community. (Suschnigg, 2012) FUCVAM helped to develop one of the earliest successful housing cooperatives among low-income families, and has therefore inspired many other similar projects.

6.1.3 La Fundación de Promoción para el Cambio Socio-Habitacional

La Fundación de Promoción para el Cambio Socio-Habitacional (PROCASHA) is a non-profit institution in Bolivia fighting housing problems with experts from different disciplines e.g. architects, lawyers and social workers. PROCASHA was officially founded in 2001 to be a forum for analysis, research and development of high-quality standards of living. (PROCASHA, 2012) The institution's vision is to improve quality of life for low-income families in Bolivia as well as to implement "social housing policies" and encourage studies and research. Another central goal of PROCASHA's work is to promote sustainability as a pillar when developing self-help cooperatives. The institution has three principles to get adequate houses: participatory action, technical advice and collective ownership. (Landaeta, 2010)

6.2 Housing cooperative projects

Housing standards in Cochabamba are low and half of the inhabitants do not own their own dwelling. In rural parts of Cochabamba people live in small communities, approximately 20 to 40 families live together and share a well from which they collect their water. There are current housing projects in Bolivia in order to improve the standard of living for suburban families outside Cochabamba. (Palm, 2010)

6.2.1 Maria Auxiliadora

The first project in Bolivia that can be resembled to the cooperative housing model was in Maria Auxiliadora, located 6 kilometers outside Cochabamba and influenced by cooperatives in Uruguay. The project was originated by 60 women who bought the land and started to develop housing plans, later financially assisted by the NGO's PROCASHA and Pro Habitat. This differs from the normal cooperative model, where organizations are involved from the start of the project.

The land was divided into several plots of different size and cost: a plot of 200 m^2 priced at 600 USD and a 300 m^2 in the corner at 900 USD. The first house was built in 2000 and in 2003 there were 50 houses. The population in the community is still increasing, and the final cooperative is estimated to house 350 families. The project in Maria Auxiliadora uses a savings system called Pasañacu, a system based on family income with two different funds. At the end of each month, one family from each fund gets financial means to start building their house. On the last Sunday in every month, there is a local meeting for people in the cooperative, discussing the project and its progress as well as working on houses and clearing plots for future houses.

At present, there are no proper water sources in Maria Auxiliadora and every week trucks supply the cooperative with water which is later stored in barrels. A barrel of water costs 3 Bolivianos (approx. 0.4 USD) and this quality of water is used for washing clothes and cleaning since it easily becomes contaminated when stored in the barrels. Drinking water, on the other hand, is purchased in bottles from the grocery store. Sanitation is also poor; most of the families do not have improved toilet facilities. There is no good refuse system either, refuse collection is too expensive and instead people compost their organic garbage and throw the rest of the garbage and waste into the nearby river. (Hansson & Olousson, 2004)

6.2.2 COVIVIR and COVISEP

COVIVIR, an ongoing project involving 26 families, is located in the municipality of Sipe Sipe in the outskirts of Cochabamba. The idea of this project is to use three houses for family dwellings around a community center where people can meet and socialize. The housing cooperative is located outside the city limits since land prices are significantly lower here. Furthermore, it is located beyond municipal water and sanitation supply, leaving the cooperative themselves responsible for this issue. (Palm, 2010)

Figure 5 Construction of COVIVIR (Rauch, 2012)

Figure 6 Women shaping reinforcement bars in COVIVIR (Rauch, 2012)

Another ongoing project in this area is COVISEP, intended to be a self-help project with help and supervision from PROCASHA. The purpose is to help low-income people to build their own dwelling in a housing cooperative, at a low cost but with relatively high standards. The idea is that all people in the housing cooperative own their house and share the ownership of the common areas with all the other people. (Landaeta, 2010)

Figure 7 Computer model of the housing cooperative COVISEP (Landaeta, 2010)

7 Criteria for a sustainable water and sanitation solution

When developing technical solutions, it is essential to identify the problems that need to be solved and consider the specific circumstances in each case. A successful method in this task is to specify criteria based on problems or difficulties with water supply. With these criteria as a foundation, the selection of technical solutions can be limited. The United Nation Human Rights have specified criteria based on the fundamental rights of humanity, these are guidelines which can be applied on different situation. The fact that they are widely defined and generalized makes it vital to adapt the criteria to the current conditions.

United Nations Human Rights have formulated the following criteria for water and sanitation:

Availability*: The human right to water is limited to personal and domestic uses and foresees a supply for each person that must be sufficient for these purposes. Likewise, a sufficient number of sanitation facilities have to be available.*

Quality: *Water has to be safe for consumption and other uses, so that it is no threat to human health. Sanitation facilities must be hygienically and technically safe to use. To ensure hygiene, access to water for cleansing and hand washing use is essential.*

Acceptability: *Sanitation facilities, in particular, have to be culturally acceptable. This will often require gender-specific facilities, constructed in a way that ensures privacy and dignity.*

Accessibility: *Water and sanitation services must be accessible to everyone in the household or its vicinity on a continuous basis. Physical security must not be threatened when accessing facilities.*

Affordability: *Access to sanitation and water must not comprise the ability to pay for other essential necessities guaranteed by human rights such as food, housing and health care.* (UN, 2008)

It is obvious that these criteria are difficult to fulfill at some locations, not least in developing countries where the economy constitutes the main constraint. UNICEF describes three situations where water supply is particularly complicated:

- *"The resources of safe water available in the area are limited, situated at some distance and/or difficult to access*
- *Financial resources are limited, and insufficient to meet the high costs of extensive pipe-work and pumping*
- *The technical expertise - the trained workforce and institutional capacity - required to design, establish and operate extensive pumping and piped systems may also be lacking"* (UNICEF, A Water Handbook, 1999)

All these constraints can be related to the situation in Cochabamba's suburbs, which put high demands on the technical solution: It has to be relatively advanced to fulfill the requirements on availability (i.e. access the water), easy to operate and maintain, besides, all costs has to be minimized. It is also of great importance that the solution is future sustainable.

8 Extraction of water sources

"When the well is dry, we know the worth of water. " (Franklin, 1746)

When deciding which water resource and system to use in development of new settlements, it is preferable to have multiple choices of water sources e.g. ground water and surface water. Techniques on how to extract these resources are presented in this section.

8.1 Ground water extraction

Of the world's total free fresh water recourses (the water bounded in glaciers excluded) 97.4 percent is water in the ground. (Fransson, 2012) When evaluating water in the ground as a resource the possibility of accessing it is of great concern. Water can be accessed in three different formations: as ground water, subsurface water or in springs.

Water will reach into the ground when infiltrating through the voids between the soil particles. As soon as the water breaks the surface of the ground it becomes subsurface water (underground water). The subsurface water is divided into an unsaturated and a saturated zone where the unsaturated zone is the zone where the voids contains water but also a lot of air. In the saturated zone the voids are filled with water and it is in the saturated zone that ground water will appear and where springs and wells can be supplied by subsurface water. (King Country Planning Division, 2012)

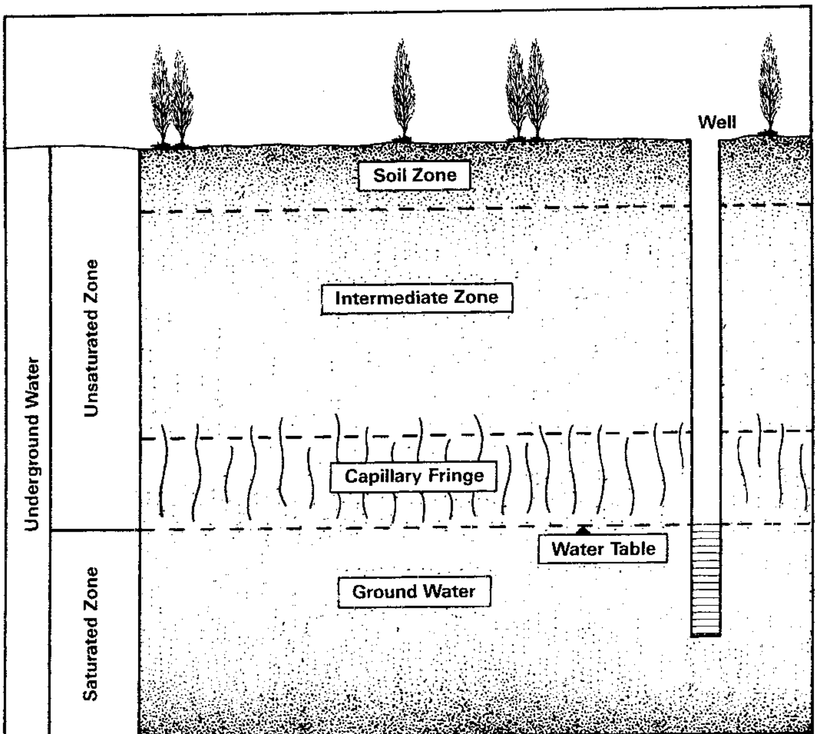

Figure 2.2 Zones of Underground Water

Figure 8 Zones of subsurface water (King Country Planning Division, 2012)

In certain geologic formations the ground water will reach the surface of the earth and springs will appear. Normally springs occur where an impermeable ground layer blocks the underground water flow, through fissured rock or in an artesian aquifer where the internal pressure of the ground water is greater than the atmosphere's. When the water has reached the surface of the earth it can either accumulate in the opening as a spring or flow directly into a river or resemble recipient. (WHO, 2012)

8.1.1 Artificial recharge

The idea of artificial recharge is to increase the infiltration or water flow to the ground water to allow a greater yield. To achieve this, surface water can be led through infiltration basins (e.g. a recharge dam) or directly through a borehole to the aquifer. When creating such a system the recharge water must be sufficiently treated to motivate the construction. The aquifer must also be extensive enough to make the storage of water possible and the soil in the water basins must have right permeability to assure a good infiltration. (DWAF, 2004)

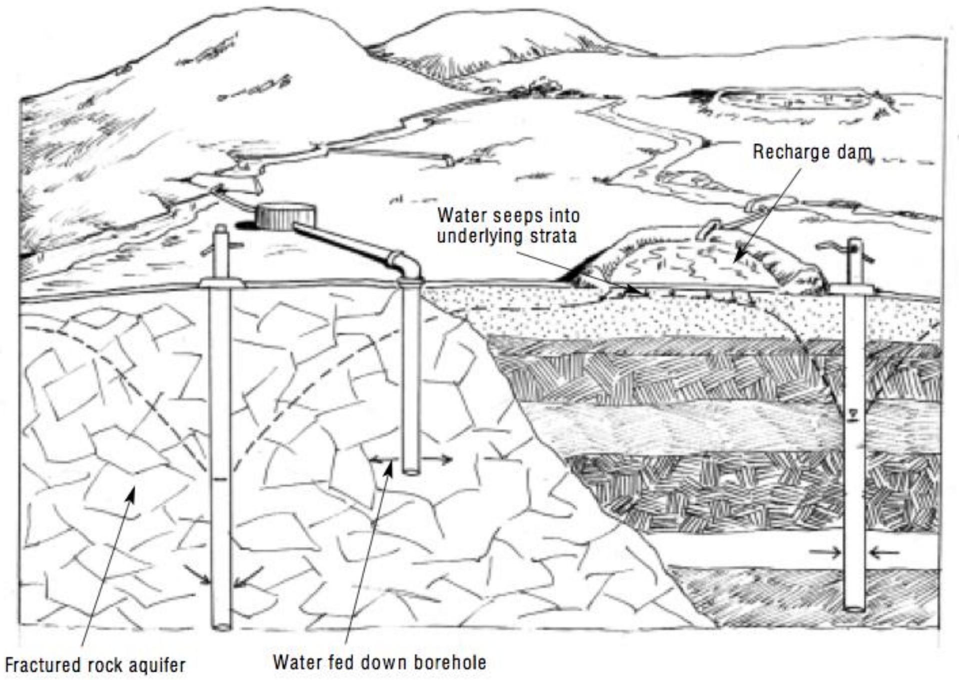

Figure 9 Artificial recharge through recharge dam and borehole (DWAF, 2004)

An artificial recharge system can be rather complex depending on size and need for treatment. Hence the system requires both professional assistance in the construction and puts high demands of maintenance. In the construction phase, professional assistance is needed to assure recharge water quality and suitability of the site as well as to design the recharge system. In the daily attention the infiltration basin must be kept clean, the efficiency of the well must be kept high and the water quality must be satisfying. This assistance together with the water treatment systems, the construction of the basin or drilling of borehole will accordingly be the major costs of system.

Advantages of the system are the increased underground storing capacity and storage of surface water to prevent contamination and evaporation. The limitations of the system are the high demands on construction and maintenance and the surface water may contaminate the ground water. (DWAF, 2004)

8.2.2 Spring water protection

The idea of spring water protection is to access a ground water flow and lead it to a reservoir without exposing the water to contamination in the air or in the surface water. (Water Aid, 2012)

To establish a fresh water system through treatment scheme, using spring water:

"Excavating the spring until the water emerges from stable ground;
Construction of a ***spring capture chamber****;*
Construction of a sedimentation chamber;
Construction of a storage reservoir to accommodate fluctuations in demand;
Construction of diversion drains and ground stabilizing structures, where required;
And
fencing and establishing grass within the spring area."

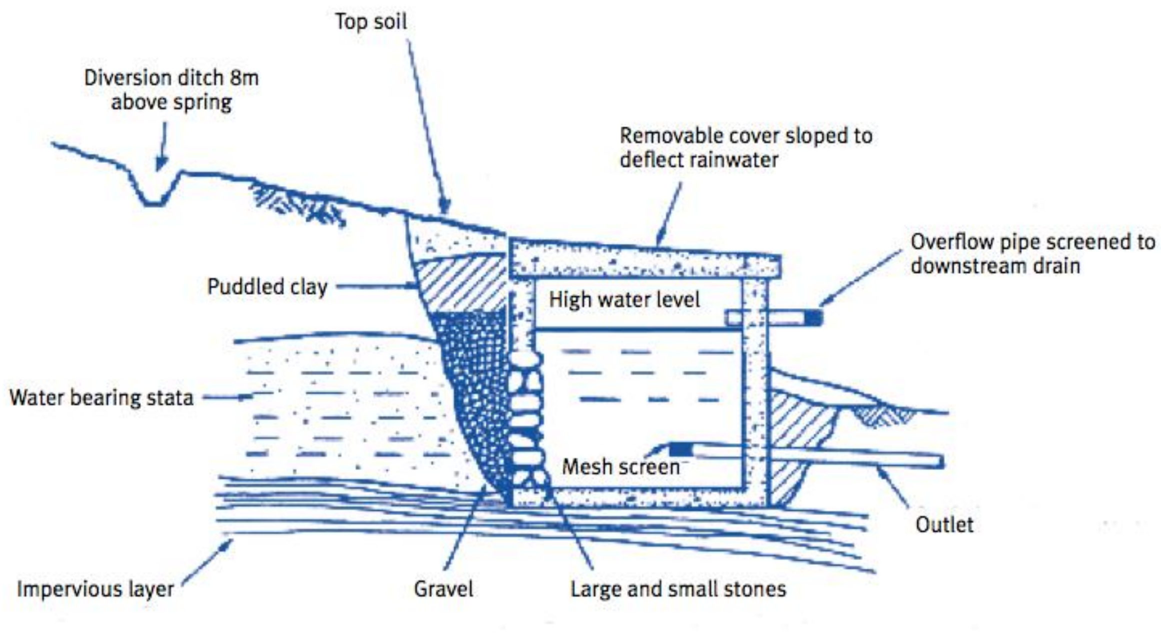

Figure 10 Section through a "spring capture chamber" (Water Aid, 2012)

The water is fetched from spring flow and lead in pipes through these constructed treatment chambers.

When constructing such system it is of great importance that the spring flow is treated with caution and may flow freely at all time, otherwise the water flow might change route and the system will be useless. The flow might as well vary a lot by the season.

Besides that the area around the withdrawal should be kept free from polluting sources like litter or latrines, vegetation should be kept low to avoid roots to destroy the constructions and the components of the spring capture chamber.

The main costs of the system are the tanks, building material and labor – which makes the price very much depending on the size and need of water treatment. The construction of the capture chamber can be performed by local craftsmen, which might reduce the costs.

Advantages of spring water protection are that they: can be built by inexperienced locals, can protect the water from pollution, do not affect the water table and is generally inexpensive. The systems limitations are the seasonal yield and the risk that the ground water flow changes route. (DWAF, 2004)

8.2.3 Drilling a new well

Another method of extracting ground water is through drilling to the aquifer. The principle is to create a borehole and after the ground water is reached, the water can be elevated to sufficient height. There are lots of different situations where the procedure will differ in a wide range. Factors which affect the choice of construction are ground conditions, equipment, need of treatment, power sources and skills. Before starting to drill a suitable aquifer must be found. To do this professionals are often consulted to test the characteristics of the ground. (DWAF, 2004) For drilling, power systems like human power, electric engines or diesel engines will be used. The elevation will mainly be done by rope and bucket or with a pump and after that the water will end-up right above the borehole or be lead to a reservoir like a tank, a basin or a lake. (WHO, 2012)

Concerning the drilling, choices will be made depending on the size of the yield and the soil characteristics. Boreholes can be made in many different sizes. Normal sizes of the diameter are between 100 and 320 mm – the bigger the hole, the greater is the yield. Rotary percussion drilling is commonly used in hard rock and mud rotary drilling is common when it comes to soft sediments. In the decision about the depth of the boreholes, consideration should be given to the seasonal change of the groundwater level to avoid that the well going dry when the water level is low.

The cost for drilling a well is dependent on the soil character where surveys, expert consultations and actual drilling will be major costs. Maintenance work consists mainly of cleaning the well from clogging and controlling the extraction to prevent the borehole from running dry. Extraction can be made through all sorts of ground, the system is quickly and efficiently created and it is a reliable water source. The disadvantages of extraction through drilling are the risk of clogging, the inappropriate use of low-yield aquifers, the need of experts, difficulties of maintaining the wells and high costs of boreholes. (DWAF, 2004)

8.2.4 Digging a new well

Digging a well is almost the same principle as drilling the well. It differs some though in performance where only human power is utilized and in construction where the size of the hole usually is much bigger. To optimize the construction the well diameter should be at least 1.2 meter to fit at least two workers. While the hole is being dug, a lining will be built to protect the well from side collapse and prevent contaminated surface water to infiltrate into it. After the ground water is reached, a choice is made whether the well will be protected or unprotected. An unprotected well has nothing covering the dug hole, which results in easy access but high risks for contamination and falling in. To construct a protected well a few more steps are required:

"A headwall or protective collar that prevents surface water from entering the well, and children and animals from falling in;
A well cover which is cemented onto the collar and leaves a small, central hole for lifting water using a bucket;
A windlass which is used to raise and lower a bucket with a hook on which the bucket should be hung when not in use; and
A drainage apron and soak-away which ensures that spilt water will drain away and not dam up around the well, causing contamination and health hazards."

To minimize the contamination and to create an easier access, a hand or motor driven pump can be installed. The maintenance of a hand dug well is partly to clean and repair the water-lifting device, but mainly the water treatment. A recommendation concerning the treatment is to routinely add some kind of disinfection substance. When it comes to capital requirements, the maintenance is spare and the major costs are material and labor in the construction phase. One positive aspect with dug wells is the large size of the hole, which makes the pit itself a recipient for the water. Another benefit is that the system can be maintained on household level. Disadvantages with a dug well are the risk of falling in to it and the high risk of contamination. (DWAF, 2004)

8.2.5 Sub-surface dams

The construction of sub-surface dams is meant to store water from sub-surface streams. The sub-surface streams usually occur in sandy riverbeds and the sub-surface water will remain in the ground even if the river dries out. One way of finding a natural sub-surface dam is to search for riverbeds with much vegetation despite the river being dry. (DWAF, 2004)

When building a sub-surface dam a wall is built in the presumed sub-surface flow, with concrete, masonry, block work or similar low-permeable material. The dam must as well be founded on impermeable bedrock. When the water flows the wall will block the flow and the water will be stored. To prevent the flow from changing direction the height of the wall must be carefully considered, allowing the water to often run over or through it. When the water is stored a pump can be installed for withdrawal. A common kind of subsurface dam is a sand dam, where the area behind the constructed weir is filled with sand. (Water Aid, 2012)

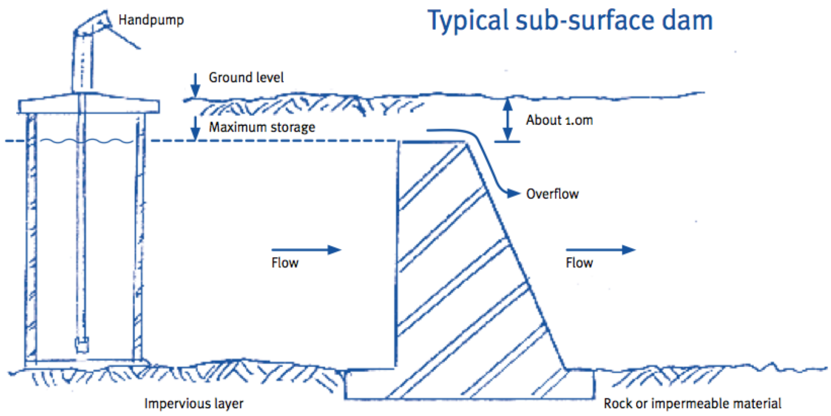

Figure 11 Sub-surface dam (Water Aid, 2012)

A disadvantage of the subsurface dams is the high risk of clogging, especially if the water has a high content of iron or manganese. This requires monitoring of the water flow to be a part of the maintenance work in order to spot reduction of the yield. The other part of the maintenance work is to change or clean the pipes to the withdrawal. Advantages with the system are the reduced evaporation and the protection from contamination offered by the ground. (DWAF, 2004)

8.3 Surface water extraction

Surface water poses only about three percent of the natural fresh water in the world and the quality differs heavily. (Lidström, 2010) In Cochabamba, surface water is a very scarce resource and the quality is bad, making it a poor alternative for drinking water supply. Where surface fresh water is more commonly occurring and of higher quality, it might be a convenient water source for drinking water supply. (Palm, 2010)

8.3.1 River water extraction

There are two essential factors to be considered when evaluating rivers as potential fresh water sources: the water quality and the reliability of the stream. The reliability of the stream depends to a large extent on the flow rate, which most often is subject for seasonal fluctuations. Low flow rates can in many cases be reason to low water quality; on the other hand, there is a risk that high flow rates contribute to a lower water quality as well, due to higher turbidity. However, it is preferable to have a rather constant flow in the stream, which unfortunately is hard to obtain at many locations, particularly in tropical countries. (Smet & van Wijk, 2002)

Once river water intake is confirmed as fresh water supply at a location, there are some general demands to consider when positioning the intake. Smet and van Wijk describe the following directives:

"Whenever practicable a river intake should be sited

- *where there is adequate flow*
- *at a level that allows gravity supply to minimize pumping costs*
- *upstream of densely populated and farming areas to reduce silt inflow*

- *upstream of cattle watering places, washing places and sewer outlets (to eliminate pollution of the water)*
- *upstream of bridges (to reduce velocity/turbulence)"*

To secure a certain sufficient depth at the site where water is extracted, some kind of weir construction might be necessary, sometimes even at a larger scale as a dam. This is also a way to deal with the fluctuations in flow rate between the dry and the rainy periods.

When selecting pumping arrangement for water withdrawal the *pumping head* is of great relevance. (Smet & van Wijk, 2002) Pumping head can be defined as the mechanical energy required per unit of weight to pump the water, expressed in units of distance. (Morrisson, 1999)

$$Pumping\ Head = \frac{Mech.\ Energy}{Water\ Weight} = \left[\frac{J}{N}\right] = \left[\frac{kg \cdot \frac{m^2}{s^2}}{kg \cdot \frac{m}{s^2}}\right] = [m]$$

If the pumping head is below 3.5-4 meters, a positive displacement pump may be used and the water can be pumped directly from the river bank as demonstrated in Figure 12. If the flow is relatively low and there is no significant risk for rolling stones or larger floating matter such as branches, the intake may be placed unprotected in the river, otherwise a protection arrangement is needed. A solution for the simplest case, low pumping head and unprotected intake, is demonstrated in Figure 12.

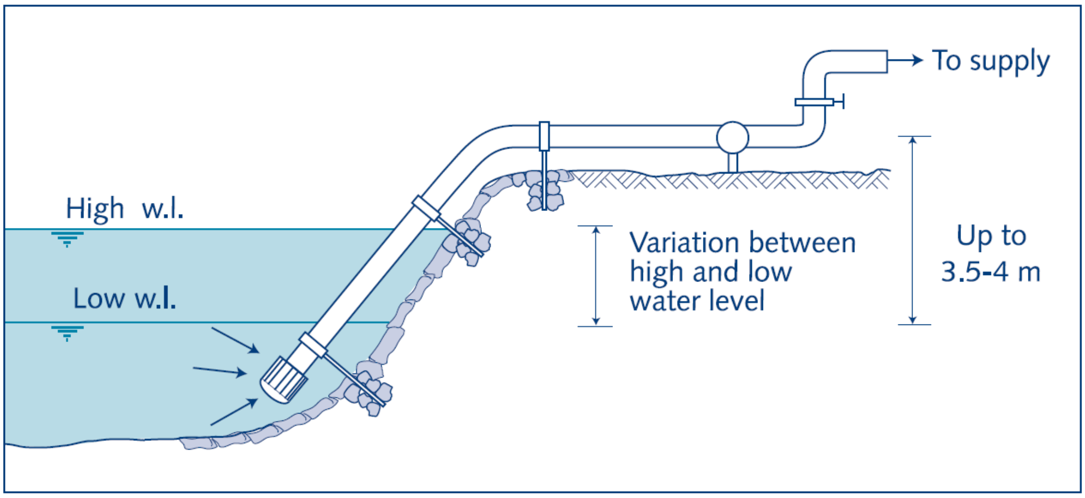

Figure 12 Direct unprotected intake from river bank using a suction pump (Smet & van Wijk, 2002)

Another relevant solution is to implement infiltration drains under the riverbed. As the water infiltrates through the river bed, it reaches a drainage which leads the water to a subterranean tank. This method requires a leachy sand or gravel layer in order for the water to infiltrate properly. The water is then drawn up to ground surface with a submersible pump; hence it is independent of pumping head. It is advantageous to use this infiltration method since the water is purified during the sand infiltration. (Smet & van Wijk, 2002)

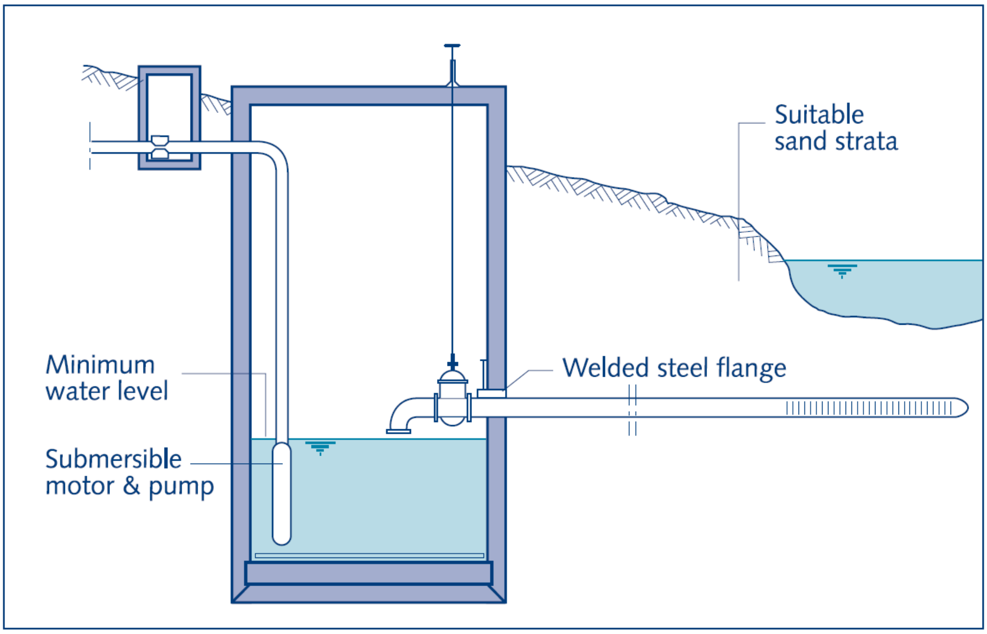

Figure 13 Intake through infiltration, drainage pipe and a subterranean tank (Smet & van Wijk, 2002)

In cases with impermeable river bed and high pumping head, the construction may be a combination of the two main principles described: An intake placed in the river leads the water to a sump close to the river, where it is later pumped to surface. However, the water is purified during the infiltration process, which is advantageous.

8.3.2 Lake water extraction

Lakes have some beneficial natural purification processes; these involve aeration, bio-chemical processes and sedimentation of solid particles. Although the water quality in general is not even comparable with ground water quality, lakes do in many cases work as reliable and sustainable fresh water sources. The water quality usually varies with withdrawal depth for many different reasons and one major reason is thermal stratification. In some cases flow rates are low, depth is relatively high and there is no significant action of turbulence. These conditions prevent the warmer surface water from mixing up with the deeper strata, creating stratification due to temperature differences. This common phenomenon influences water quality since it creates a variation in concentration of different substances due to various temperatures. This is one of the main parameter to consider when setting the intake depth. Since a relatively stable water temperature is wanted in distribution, it is beneficial to establish the intake at high depth, where the temperature fluctuations are smaller. The potential presence of unwanted algae in upper water layers excludes the surface strata from the intake point selection. It is, however, important not to place it too deep; water withdrawn close to the lake bed may contain bottom particles, besides, the pumping costs increase significantly with higher depth.

There are multiple principles for intake constructions, all suitable for different situations depending on lake depth, water quality and intake depth. At many sites the lake depth varies over the year due to dry periods and rainy periods. This puts a demand on the construction to be adaptable to the current conditions. (Smet & van Wijk, 2002) A selection of basic intake principles is demonstrated in Figure 14, 15 and 16.

Multi-level intake

In deeper lakes there is an advantage in withdrawing water at various depths to achieve a suitable mixture of water from the different layers.

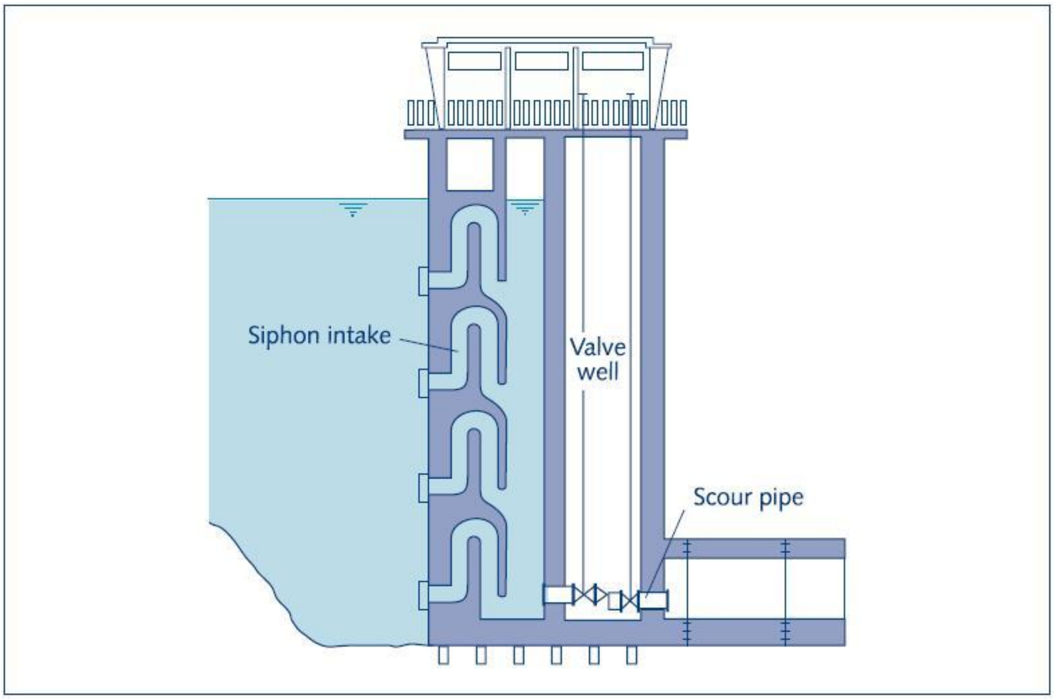

Figure 14 Multi-level intake through siphons at various levels to secure stable water quality (Smet & van Wijk, 2002)

Lake bed intake

In shallow lakes, the water withdrawal is usually on the lake bed through an elevated intake "well". This principle ensures exclusion of bottom particles in the water.

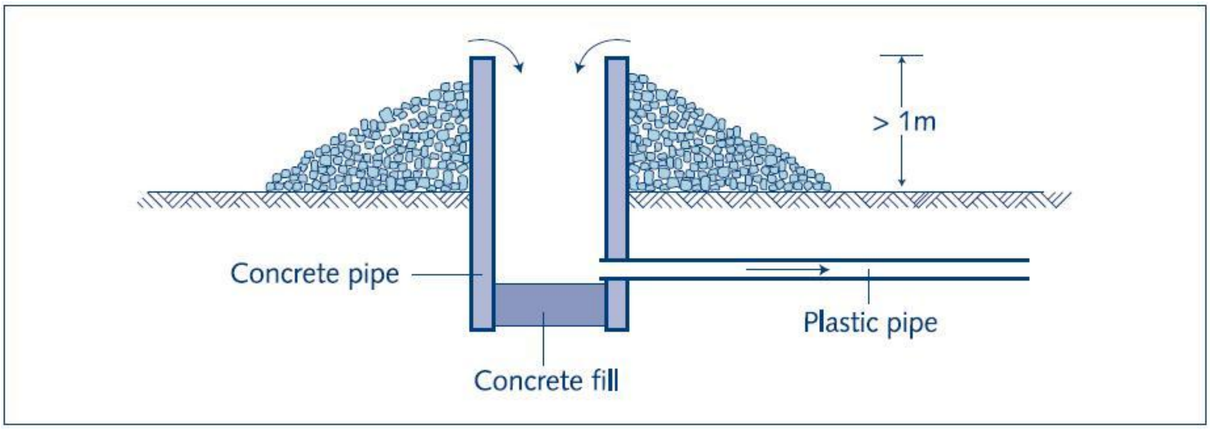

Figure 15 Elevated bottom intake solution in shallow lake (Smet & van Wijk, 2002)

Variable level intake

If water surface level varies a lot it is desirable to adapt the intake level to different periods of time. There are a few methods for this purpose, for example using a float as shown in Figure 16. This simple method is relatively cost-efficient, can be constructed by hand and is suitable for a low intake flow. At high flows, the plastic hose will not suffice the need, and the whole solution needs to be replaced. For such cases there are alternatives based on the same principles, but with some modifications.

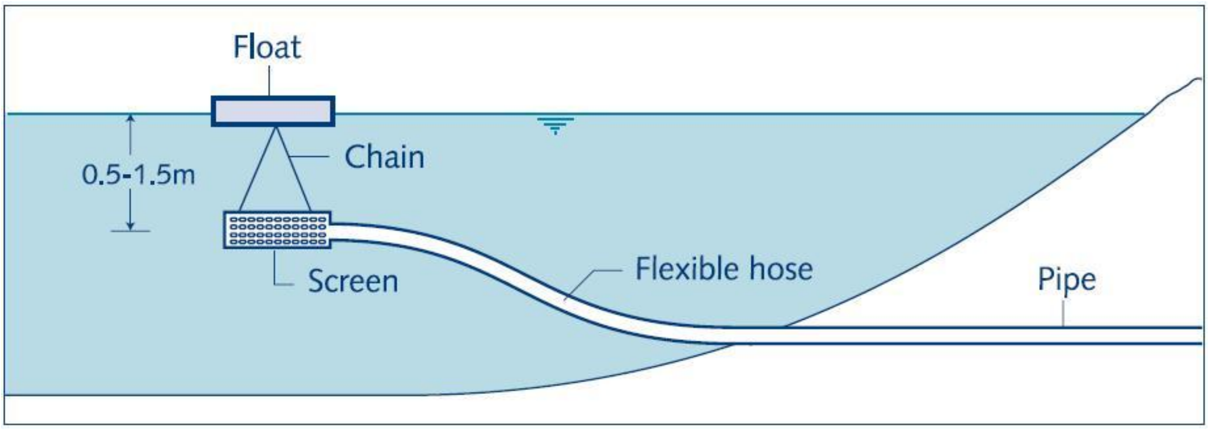

Figure 16 Intake through a screen suspended in a float to enable it to withdraw water at various depths. The water is led to land through a flexible plastic hose (Smet & van Wijk, 2002)

According to Smet and van Wijk a community of 1000 consumers requires an intake flow of only 1.4 l/s, based on a consumption of 30 liters per capita a day. This would require an intake pipe dimensioned at 150 mm in diameter, corresponding to an entrance velocity of 0.1 m/s.

8.4 Rainwater harvesting

Rooftop catchment systems are constructed by using gutters and downpipes made out of local wood, bamboo, galvanized iron or PVC. Thereby gathering rainwater caught on the roof of a building, and leading it into storage containers consisting of simple pots to large ferrocement[5] tanks. Tentatively, a detachable downpipe or a first flush device should be included in order to exclude the initial 20 liters of run off to waste, which is mostly contaminated with leaves, dust, bird droppings and insects. Alternatively, a small filter consisting of gravel, sand and charcoal can be used before the water enters the storage tank. Subsequently, the water can be extracted from the tank by using a tap, hand pump or a bucket and rope system. Proper use of rainwater harvesting technology should yield almost one liter per horizontal square meter per mm rainfall and is thereby usually sufficient for drinking purposes. (Brikké & Bredero, 2003)

[5] The standard cement is reinforced with more steel or fiber at a closer spacing than traditional construction. (Ferrocement, 2012)

The International Rainwater Catchment Systems Association has formulated following environmental requirements for RWH:

- *Rainfall should be over 50 mm month^{-1} for at least half of the year (unless other sources are extremely scarce)*
- *Local roofs should be made from impermeable materials such as iron sheets, tiles or asbestos*
- *There should be an area of at least 1 m^2 near each house upon which a tank can be constructed*
- *There should be some other water source, either ground water or (for secondary uses) surface water that can be used when the stored rainwater runs out* (IRCSA, 2012)

The dimensions of the storage tank should correspond to the material available and the required size of the tank which in turn depends on rainfall patterns and the water demand. In some areas e.g. South Africa storage of up to nine months might needed. (DWAF, 2004)

It requires regular maintenance and in case there is no downpipe or first flush system, a caretaker has to manually divert the first 20 liters. Chlorination of the water may be necessary in order to make it drinkable. If rooftop harvesting systems are constructed on a school or other communally shared roof e.g. where several households have connected their roof to one shared tank, the establishment of a water committee might be needed in order to control eventual collection of fees and water use by each family. (Brikké & Bredero, 2003)

RWH does have limitations and is not suited to be used as the main water supply system but rather as a supplement to existing systems. (IRCSA, 2012) Nevertheless, it is suitable to use in developing countries with one or two rainy seasons and an average annual rainfall between 250 to 750 mm. Problems that might occur are: corrosion of metal roofs and gutters, contamination of uncovered tanks, leaking taps and neglect of maintenance. Open water surfaces may also provide a breeding place for mosquitos, hence increasing the risk of diseases like malaria. (Brikké & Bredero, 2003) However, the technology can be advantageous in several ways due to; its ease of applicability and water quality maintenance, the sense of ownership given by a household level collection and the possibility to be constructed from locally available materials. Additional consequences are reduced soil erosion and flooding around the house and also the ground water is less likely to be over exploited if it is used in conjunction with RWH. (DWAF, 2004)

9 Water treatment

"The children who have no clean water to drink, the women who fear for their safety, the young people who have no chance to receive a decent education have a right to better, and we have a responsibility to do better. All people have the right to safe drinking water, sanitation, shelter and basic services." (Ki-moon, 2012)

Water treatment can be divided into household level and community level involving various devices and techniques. However, the overall purpose of treating the water is to make it acceptable for use by improving following attributes:

- The color
- The taste/odor
- The chemical and bacterial content
- The turbidity
- The hardness

The aim is to provide a cost-effective treatment process which is adapted to rectify prevailing water conditions e.g. murky water or high concentrations of arsenic, fluoride and nitrates. (DWAF, 2004)

9.1 Treatment plants

When investigating potential drinking-water supply sources, it is important to identify hydrological and geological conditions as well as current land use to determine potential contamination sources. Other potentially polluting natural factors (e.g. wildlife and vegetation) and human factors (e.g. wastewater discharge) should be identified and avoided as much as possible. By understanding the reasons for variations in raw water quality, the requirements for treatment can be lowered.

The aim when designing water treatment works is to create a complete treatment process consisting of a cost-effective combination of different processes that will provide water of adequate quality. To do this it is important to properly determine the different contaminants and the appropriate measure in order to meet prevailing water standards. In order to avoid e.g. blocked filters and overloaded sedimentation tanks it is important to construct the treatment plants accordingly to known or expected variations in water quality. (WHO, 2011)

The treatment work can then be custom-built according to the assessed contaminants and the financial situation. Purification process against each specific contaminant can be read off in Appendix 1.

9.2 Slow sand filtration

Slow sand filtration is a 200-year-old procedure for cleaning water; this method relies on an artificial replica of the natural infiltration process and is still supported by the experts. Sand filtration mainly purifies the water from suspended organic material, inorganic material and may also remove pathogenic organisms. The filtration bed contains of two main layers: a gravel layer in the bottom and a sand bed which is held by the gravel. The sand bed will be soaked and have a layer of stagnant water on top; this water will provide hydraulic pressure, which forces the water to flow through the bed. On top of the sand layer there will be a coat of organic material, which the water has to pass through and react with. The cleaning process is mostly done in the coat layer on top of the sand bed, where organic materials undergo a chemical and biological process that kills harmful substances. The filtration through the sand is mostly to reduce particles that do not get stuck in the schmutzdecke, which is a name of the top layer. This schmutzdecke is the only part of the system that has to be maintained on a regular basis. The maintenance can be simplified by using a geotextile filter, which can easily be removed when the permeability getting low. This does not only make it easier to clean the top, but also prevents disorder in the top layer of sand in the bed when cleaning.

There are many benefits using slow sand filtration compared to other purification methods, beds are built out of cheap materials and they have low operational costs with high functionality. Some issues with the slow sand filtrations is the space requirement, a filtration field needs lots of space and is rather slow production method. There is also a need for at least 2 beds for treatment of fresh water; this is due to the reconversion of the biological growth. The untreated water needs to have low turbidity, otherwise the organic materials may clog the system. It also has to be temperate; cold water does not benefit the biological growth, which is necessary to make the filtration efficient. This may cause polluted water to pass through without being cleaned properly. The slow sand filtration is not effective against heavy metal content in the water, which makes it less appropriate to use if there is a high concentration of this in the water that has to be cleaned.

The water will need some sort of disinfection to remove the organic particles passing through the filter, disinfection with chlorine may cause problems when it reacts with organic materials and creates trihalomethane (THM). To prevent the particles from passing through the bed, there is a possibility to install an activated carbon (CAG) sandwich filter, which removes the last organic particles. This opens up the opportunity to use chlorine before delivering the water to the households.

The water production can be estimated to be 0.1-0.2 m^3 per m^2*h, which with simple estimations leads to 2.4 – 4.8 m^3 clean water per day and square meter. According to Dr. Carmen Ledo at Universidad Mayor de San Simón in Cochabamba, the minimum amount of water needed per person is 50 litres. (National Environmental Service Center, 2000)

9.3 Chlorination

Chlorination is a simple and cheap method to obtain clean and drinkable water and protect public health. Chlorides are effective and disinfect drinking water rapidly, after 24 hours the microorganisms are destroyed by the chlorides. Waterborne diseases that cause e.g. diarrhea can simply be avoided. Without difficulty, chlorination also removes pathogens e.g. E.coli which otherwise could cause deadly epidemics. (Department of Human Services, 2006)

Mold and algae growing in water supply reservoirs and storage tanks are eliminated through chlorination. The chlorides also separate the raw water from iron and manganese, supporting removal of unwanted taste.

The pathogens in drinking water primarily consist of three types: bacteria, viruses and parasitic protozoa. When disinfecting the water, the aim is to kill or inactivate all this microorganisms. Chlorination controls the bacteria and the viruses, but the parasitic protozoa require other types of control measures e.g. raw water filter.

The concentration of chlorine can be designed to continue the protection of microbes after leaving the treatment plant. By using this method, the water keeps safe also during the transport. (Chlorine Chemestry Council, 2003) To avoid risking human health, WHO has designed a guideline value for chlorine in drinking water. The limit value for lifelong human consumption is estimated to 5ml/L. (WCC, 2008)

Even though chlorination reduces some taste and odor, there is a problem with unwanted taste and odor from the chlorine itself. To prevent this, it is useful to store the water in a tank during two weeks or boiling the water. (Department of Human Services, 2006)

9.4 Solar disinfection

Solar disinfection is a simple and low cost water treatment method that utilizes the synergy of UV-A radiation and infrared light to disable DNA involved in reproduction of bacteria and viruses, thus rendering it harmless upon ingestion. UV radiation sources are mainly natural sunlight or discharge tubes. (Burch & Thomas, 1998)

Solvatten is a patented Swedish invention which inactivates micro-organisms that cause diarrhea and disease by using solar energy. It requires 2-6 hours in the sun and can produce 20-30 liters of water which meets the WHO's Guidelines for Safe Water (<1 E.coli/100 ml water). Water containing bacteria, viruses and parasites can be treated during the products' approximated 5 year life span. (Solvatten, 2012)

Figure 17 Solvatten (Solvatten, 2012)

A more common method for taking advantage of sunlight in order to disinfect water is by using regular plastic bottles. Bottles that should be used are 1- to 2-litre clear PET (plastic polyethylene terephthalate) bottles or transparent and colorless glass. They are filled up with the potentially contaminated water source and then exposed to the sun for 6 hours on sunny days or 2 consecutive days if the sky is more than 50 percent cloudy. Water with high levels of turbidity should undergo filtration, flocculation or sedimentation to prevent suspended solids from blocking the ultraviolet radiation. (Clasen, 2009) The heating process can be enhanced by placing the bottles on a metal surface e.g. a corrugated metal roof and the disinfection can be speeded up by shaking the bottle thoroughly both before exposure and every hour during exposure, thereby adding oxygen to the water. Solar disinfection is mainly used to treat small quantities of water and is thereby mostly appropriate to be used at household level. As the bottles do not offer residual protection they should be kept tightly closed until they are used. Bottles and caps should be cleaned on a regular basis and replaced every 4-6 months as they become scratched and aged by the sunlight.

However, there are some limitations with application of solar disinfection technology. It is unable to be used with larger containers and the application is dependent on the climate. During days of continuous rainfall this technique will not perform satisfactorily and an alternative, such as boiling, should be used. (NWP, 2010)

9.5 Boiling disinfection

The principle behind water boiling disinfection (also called pasteurization) is simple: heat the water to kill all kinds of waterborne disease-causing pathogens. A temperature of 55-60°C for about ten minutes is usually considered enough to destroy all viruses, bacteria, fungi etc. When there is difficulties in temperature measuring, the water can be kept boiling (100 °C) for just a few minutes to make sure the water is drinkable afterwards. The secondly mentioned method is always safer since it also eliminates the risk of errors in measurement. (World Health Organization, 2012)

10 Distributional systems

"High quality water is more than the dream of the conservationists, more than a political slogan; high quality water, in the right quantity at the right place at the right time, is essential to health, recreation, and economic growth." (Muskie, 1966)

To connect a household to a water resource, a distributional system is required. The system mainly consists of a piped network and some kind of reservoir. (SSWM, 2012) Another important distributional process is to provide the households with hot water.

10.1 Water supply system

The main idea of a water supply system is to create a flow in the water and lead it to a decided point. When affecting a flow the main controlling parameters are: pressure, friction, size and gravity. The water will obtain a certain energy level through elevation to a certain height or through adding pressure. After that the flow is lead through the system, losing its kinetic and potential energy due to the loss of height and the friction in the pipes.

A water supply system consists of four major elements:

- A piped system to lead the water between two given points
- Reservoirs to store the water
- Pressure creating stations like pumps to create the flow in the system
- Various components mainly valves to control the flow

When it comes to the design of a water supply system, professionals should always be consulted to improve economy and reliability. (UNICEF, A Water Handbook, 1999)

10.1.1 Water pumping

In all steps of the water supply cycle, it is essential to be able to move water both vertically and horizontally. To generalize, all form of water movement is based on pressure difference which is acquired naturally or artificially by using a pump. Pumping is therefore of great significance in all steps of the water supply cycle. There are three basic pumping principles: Positive displacement pumps, Centrifugal pumps and Hydraulic ram pump.

Positive displacement pump

This is the oldest method for pumping liquids and there are many different types of displacement pumps. Sprinkler Warehouse describes the principle as the following: "*positive displacement pumps - moves water by alternately trapping a fixed amount and then forcing that trapped water into the discharge pipe*". (Sprinkler Warehouse, 2012) There is an expanding cavity on the suction side, creating a low pressure where water flow in. On the discharge side the cavity is decreasing and pressure is rising which causes the water to flow out. (EMT, 2012) Examples of pump types using this method are suction pumps, traditional hand-pumps and gear pumps (Figure 18).

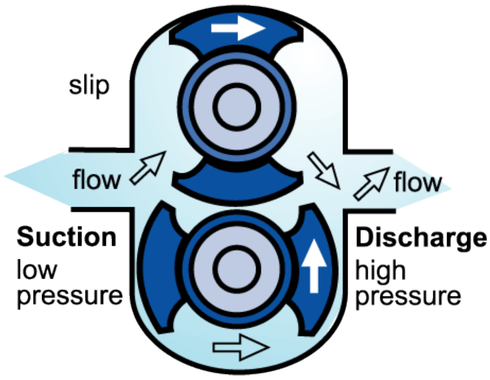

Figure 18 Positive displacement pump (EMT, 2012)

Centrifugal pump

The centrifugal pump is, as a result of its efficiency and relatively low price, the most used pump type in the world. The principle is fairly simple; when rotating the impeller a pressure difference is built as the water is forced to flow from the center of the impeller and out along the blades. Lower pressure in the inlet (suction side) and higher pressure in the outlet (discharge side) causes the water to flow through the pump. The design of this kind of pumps varies a lot although they are all based on the same principles. Figure 19 illustrates a basic workflow of a centrifugal pump. (Grunfors, 2012)

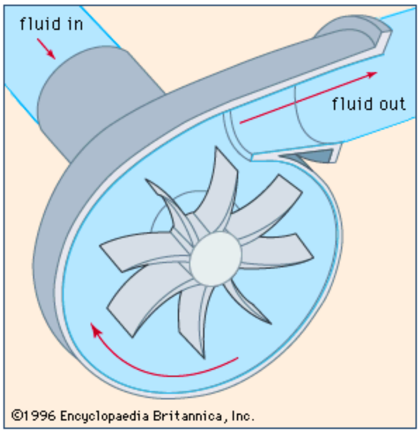

Figure 19 Centrifugal pump (Britannica, 2012)

Hydraulic ram pump

This type of pump differs in many ways from the two earlier mentioned. The most significant difference is that the hydraulic ram, also called impulse pump, does not need any kind of motor to operate. Hence these pumps do not really have an operating cost; although it is a fundamental requirement that the water has a low flow rate. The hydraulic ram can be used in e.g. streams, ponds or springs where the flow rate is relatively low. (Jennings, 1996) The principle is based on the fact that flowing water has momentum, so when the water stream is stopped abruptly, a pressure pulse is created. This pressure pulse, which can be compared to a hammer blow, moves the water to a tank where high pressure is obtained. Due to the overpressure in the tank, the water can be lifted vertically. The hydraulic ram pump is rather inefficient, only one ninth of the water volume passing through the waste valve is pumped (Figure 20). To extract a significant amount of water the flow has to be relatively high, besides, the flow rate has to be low in order to make the system work well. (Smith, 2007)

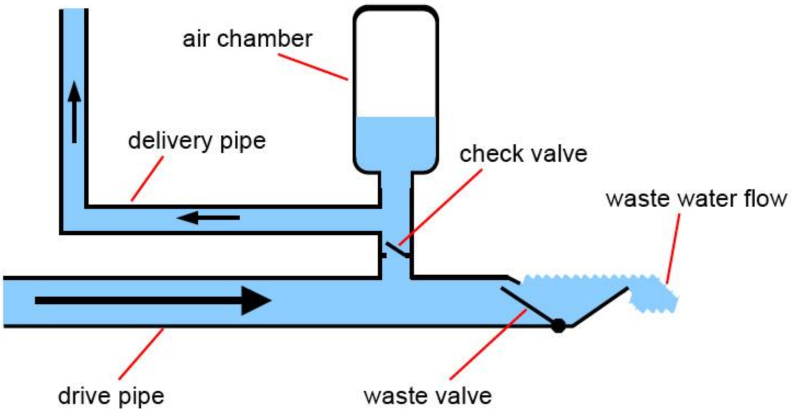

Figure 20 Hydraulic ram pump (Akvopedia, 2009)

10.1.2 Pipes

The pipes differ in choice of materials depending on required performance. Common materials are:

- Galvanized iron – good for high-pressure pipelines and areas where burying of the pipes is inappropriate, this is a more expensive solution
- Poly vinyl chloride (PVC) – Low-pressure pipelines which are more fragile and vulnerable to sunlight and require to be buried
- High-density polyethylene – Similar to galvanized iron with easier handling, less expensive but a bit lower performance (UNICEF, A Water Handbook, 1999)

10.1.3 Reservoirs

The reservoirs in a water supply system become an essential part of the scheme because they even the water production and provide storage which leads to an effective and profitable system. This means that water can be extracted and treated at a constant flow even if the household requires different flows during the day. The storage function makes it possible to provide a household with water at all times even if the demand is lower than the outtake.

Reservoirs can be constructed with three different principles:

- Low reservoirs – lies on a low level and the distribution is done through pumping
- High reservoirs – lies on a high level and distribution is done by gravity
- Hydraulic accumulator – a closed cistern filled with partly air and partly water, where the pressure of the air will increase as more water is added (Lidström, 2010)

Two common solutions of reservoirs are either an elevation tank or a pneumatic tank:

Elevation tank

An elevation tank is a high reservoir often built in concrete. A pump connected to the water source will elevate water to a tank placed above the regarded water outtake. An electric switch will start the pump when the water reaches below a certain level, and stop when the tank is filled. The advantage of an elevation tank is that smaller particles accumulate at the tanks bottom instead of reaching and destroying the pipe-system.

Pneumatic tank

A pneumatic tank is a hydraulic accumulator. The pump connected to the tank will regularly pump water into the tank when the air pressure reaches below a certain level. This tank will require a pump with significantly higher capacity than the elevation tank. Advantages of this tank are a reduced pressure difference for high buildings eliminating the need for a tank-tower. Disadvantages are that there is a need for a large accumulative volume, otherwise the pump will start too often, and there is a higher energy consumption. (Palm, 2010)

10.2 Non-piped distribution

In many parts of the world, often rural and peri-urban, water supply has been made through people walking to the water source and collecting the water themselves.

Another common solution is through getting the water by tank trucks. In such system a tank truck is usually collecting water from a source and driving it to either a central community location or a household. When arrived, the water is pumped into hand-held containers or into other recipients like wells or tanks.

In communities where there are no municipal piped water supply systems, transported supply can be part of the distribution plan managed by the government. Outside the area covered by public supply-system people usually have to buy the water from private entrepreneurs, affecting both quality and economy. The price can then, in the worst cases, rise up to 20 times higher than the price of piped water.

When transporting water in tanks, keeping a sufficient quality is of high concern. This puts a lot of demands on the transport procedure: the tank should be made of a material that is smooth, impervious, corrosion resistant, nontoxic and non-absorbent such as stainless steel or aluminum. It is also important that the tank can be closed to exclude contamination risks. This also concerns the distribution from loading to unloading, which must be done without risks of contamination. When the tank truck has been used for other means than carrying non-food goods, it has to be approved by a liable institution after all spaces has been cleaned thoroughly.

The advantages of non-piped distribution are the mobility and possibility to quickly establish a system. The disadvantages are the high costs, low water quality, non-verified water sources and high dependence of the trucks. (SSWM, 2012)

10.3 Hot water production

There are several methods available for water heating; it can rely on e.g. solar power, electricity or waste heat. A single water heating system can cover everything from one house to an entire city. Individual water consumption varies a lot between different societies due to climate and habits. Thus two of the main parameters for selection of a system are coverage size and production volume. Some water heating methods may be scaled to fit different needs, while others are more suitable for a lower or higher need. Other vital parameters to keep in mind are the implementation cost and operational costs. (USDE, 2012)

10.3.1 Storage water heaters

A rather conventional solution for water heating is *Storage water heaters,* i.e. water is heated up in a tank using natural gas, propane, fuel oil or electricity. Heater can differ a lot in "first hour rating", which is the amount of hot water the heater can provide in an hour. The first hour rating is highly dependent on tank size and heating method. Dimensioning of a heater in each case is based on matching the first hour rating with the peak hour of the day. Another essential concern in the selection process is to determine heating method, which depends on the resources available.

The storage water heater is equipped with a thermostat, enabling heating as water temperature falls below the desired temperature. Although the heating is only activated when demanded, there is a relatively large heat loss at standby mode contributing to a high energy loss, especially if the tank is poorly insulated. This method of water heating obviously has a high operational cost, and operational costs are directly proportional to the degree of usage. The purchase cost is relatively low, starting at approximately 100 USD for small heaters. However, storage water heaters can be considered reliable with the exception that they might temporarily run out of water at heavy usage.

10.3.2 Solar heating

Solar heating is a flexible heat source which certainly is more beneficial at locations with high solar effect, although it can prosperously be used practically anywhere. A clear advantage is that it can be used in completely different contexts and magnitudes, including every level from a primitive black can or tank to a high-tech solar panel facility. This flexibility allows people to customize a solution based on demand and economic funds. The principle for solar panels is usually that there is a dark solar absorption plate covered with a transparent material layer; water passes through pipes in the construction and heats up. The heated water can either be used directly (direct circulation) or the heat can be transferred to a connected secondary system (indirect circulation). Which method to use is decided by climate data, direct circulation can only be used at locations where temperature rarely drops below freezing temperature. The solar panel can preferably be connected to an accumulator tank to raise the capacity.

Depending on reliability requirements, a complementary solution might be necessary to secure hot water supply. In such cases, the problem can be solved by connecting the solar panel to a conventional water heater to ensure a reliable flow. The operational cost of a solar water heating system is practically zero, unless a complementary system is used. The purchase cost is relatively high; a low-capacity (maximum one family) solar panel is priced at approximately 1000 USD. (USDE, 2012)

11 Sanitation

"The obvious issue is providing clean drinking water and sanitation to every single human being on earth at the cost of little more than one year of the Kyoto treaty." (Lomborg, 2012)

Wastewater treatment and sanitation are important factors to maintain a sustainable interaction with the water cycle. Usage of water should be as effective as possible with a minimum amount of water wasted and taking advantage of existing water resources without threatening the environment and hydrological cycle. Sanitation encompasses human excreta disposal systems, waste water disposal devices, solid waste disposal and drainage of surface water. (Brikké & Bredero, 2003) Sanitation solutions such as dry toilets which, based on earlier studies, have not been satisfactory enough for cooperatives in Cochabamba will not to be evaluated in this section. (Palm, 2010)

11.1 Black water management

Toilets connected to the following systems can be placed inside the house. Unwanted smells and draughts are prevented from entering the toilet by a water trap whilst using the toilet. The black- and grey water is then transported to a treatment works by a piped system or a tanker. The treatment works can vary from a simple pond system requiring no operating personnel to a highly complex system requiring 24-hour support. The purpose is however to, separate solids from liquids, destroy pathogens and dispose solid waste. The treated water is then released into a nearby river or re-used in agriculture. (DWAF, 2004)

Conventional treatment of sewage is illustrated in Figure 21. However, in developing countries the process usually is less complex and could consist of e.g. a septic tank at home for primary treatment followed by some secondary treatment technology placed at another location and appropriate for prevailing conditions. (WELL, 2012)

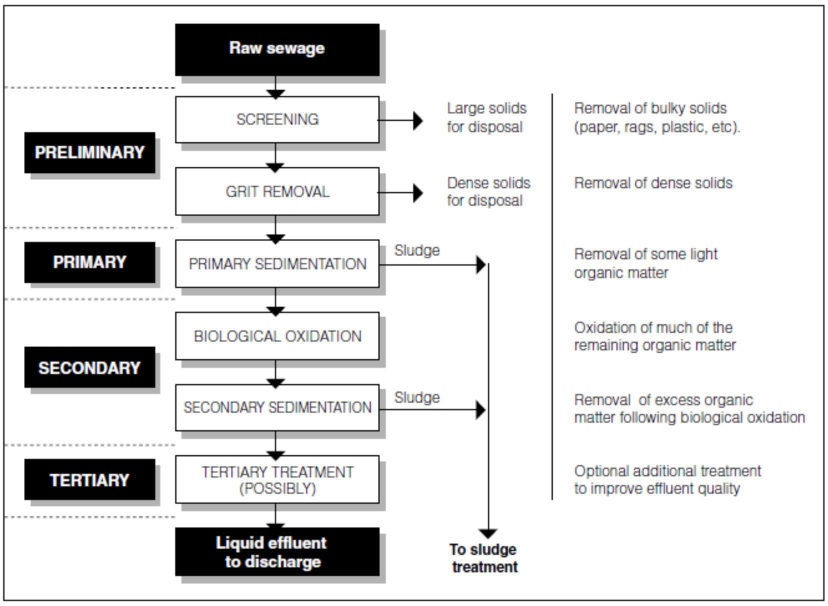

Figure 21 Schematic view of conventional sewage treatment (WELL, 2012)

Concerning operation and maintenance all systems mentioned provide high levels of comfort and convenience as the toilet is placed inside the house and the user does not have to handle any waste. However, there are some capital requirements for the components and some institutional support is needed for emptying the tanks and operating the treatment works. Thereto, a household water connection with a reliable 24-hour piped water supply is required.

To avoid surface seepage and groundwater contamination the components has to function effectively and possible leakage in the system has to be detected. Also, nitrates should be removed as they may affect the groundwater.

The systems have a couple of general limitations such as that the tanks require sufficient space on the property and the soil has to provide good drainage in order for the soakaway to function properly. The typical filling rate of the septic tank is 30 liters, per user, per year and the time it takes to fill the tank is thereby dependent on the number of users. A tanker is needed for its removal which in turn requires good access for de-sludging and an operational central sewage treatment works. Overload might occur during peak periods and social events with exception for the piped system. On the other hand, blockages might occur in the piped system if soft toilet paper is not used and if unwanted materials are disposed into the toilets.

Sludge treatment can be made using drying beds, which treat the sewage by evaporation and drainage. A simple drying bed is shown in Figure 23, it is a relatively simple construction and easy to operate. This method is efficient and leaves a dried cake of sludge, which can be used in agriculture. It is important to reduce the content of non-bio waste which will contaminate the nature if spread out in the fields.

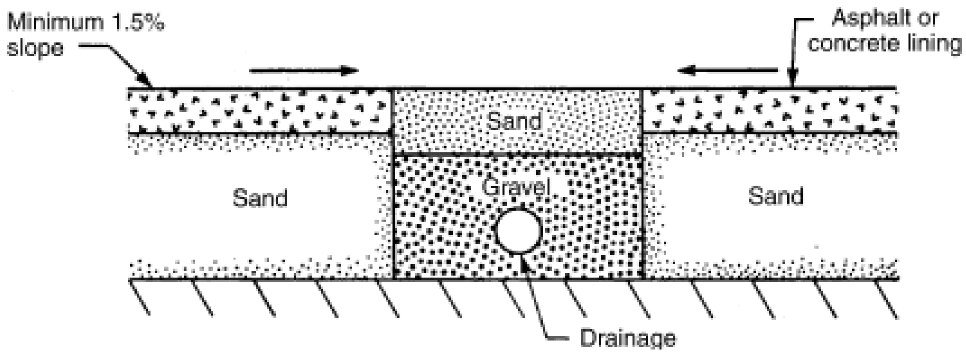

Figure 22 Typical paved drying bed construction (Nowak, 2007)

The field should preferably be refilled during early since the treatment process is three times as fast during summer as a result of the high temperature and intense sunlight. A disadvantage with the drying bed is the odor that occurs early in the process.

11.1.1 Piped system with central treatment works

In developed countries and in most urban areas a common solution is to lead all sewage water via pipe system networks to a central treatment works. The treatment works can handle large quantities of black and grey water. However, this system requires a reliable 24-hour piped water supply in order to avoid blockages and the treatment works has to be able to handle a large amount of solids. (DWAF, 2004)

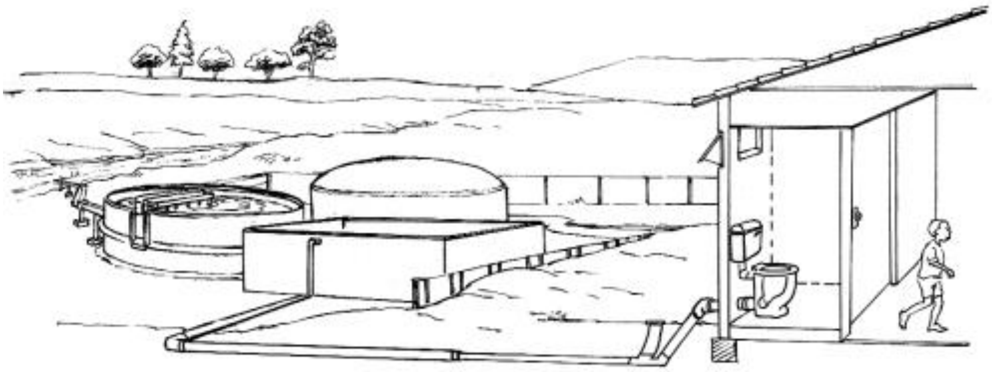

Figure 23 Piped system connected to treatment works (DWAF, 2004)

11.1.2 Septic tank & soakaway

Waste from the toilet is flushed into a septic tank in which solids are retained whilst the effluent is led to a soakaway or a constructed wetland. The purpose of a septic tank is to treat wastewater and it usually consists of a bottle-shaped plastic tank buried underground but can also be placed above ground as a large rectangular box made of brick, stone or concrete. Natural bacteria has to be allowed to breed within the tank as it digests the waste material so that treated effluent is led through the tank's outlet pipe into a soakaway or a constructed wetland. The sludge from the tank is not sufficiently treated to be used as fertilization in agriculture. The sludge should either be treated on site of transported to a treatment plant. (Gateshead, 2012)

The soakaway can consist of a circular pit filled with e.g. rubble. (BRE, 2003) As the effluent seeps through the surrounding soil, a process of natural purification happens. Bacteria occurring naturally in the soil breaks down remaining polluting materials and pathogens are eventually rendered harmless. However, adequate purification is only achieved after the effluent has travelled quite a long distance in the ground. The system does also accept grey water in amounts governed by the size and capacity of the soakaway. (EPD, 2012) Initial cost for building a septic tank in combination with a soakaway is approximately 90-375 USD including labor and materials. (UNESCO, 2012)

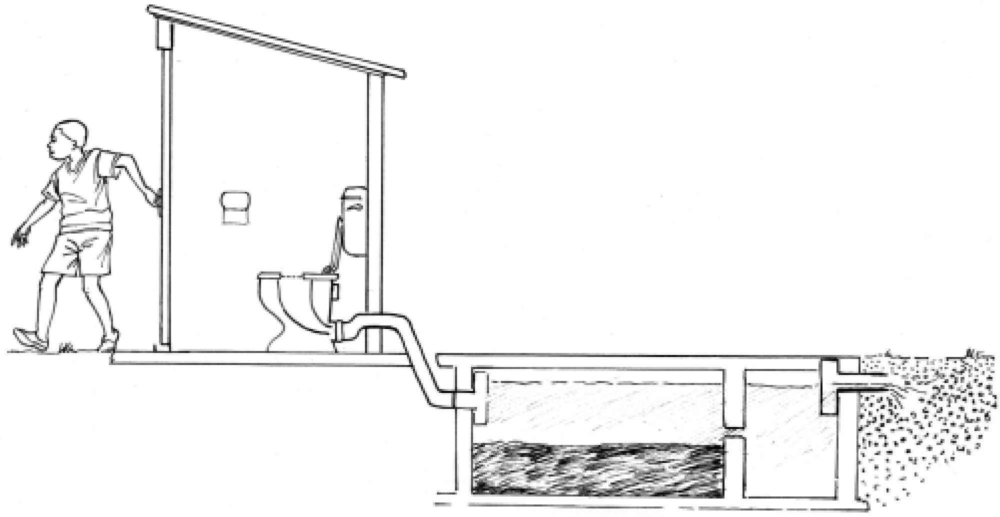

Figure 24 Septic tank and soakaway (DWAF, 2004)

11.1.3 Conservancy tank

If the ground is not permeable enough for the soakaway to function properly a conservancy tank can be used instead. Whereas toilet waste and grey water is flushed into a watertight tank which is emptied on a regular basis by a tanker and then disposed of at a sewage treatment works. The frequency of emptying decreases if grey water is separated and utilized at household level.

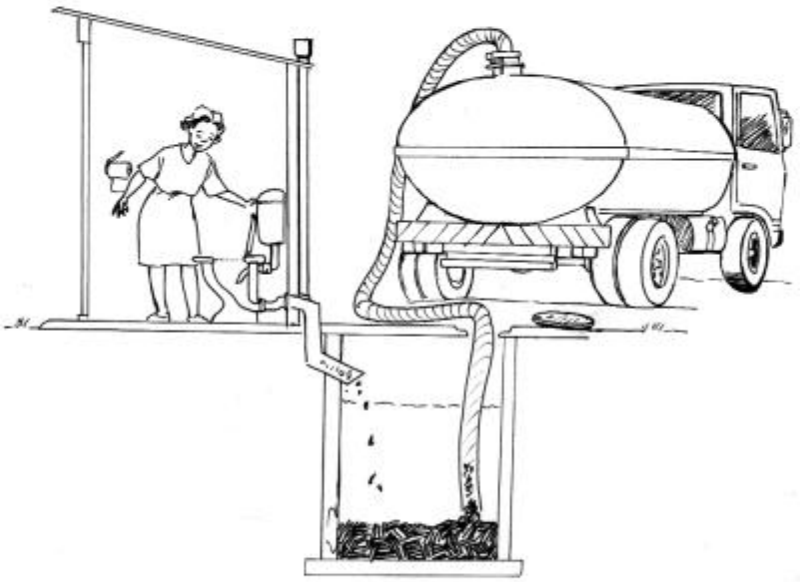

Figure 25 Conservancy tank (DWAF, 2004)

11.1.4 Small-bore sewerage

Another alternative, in case the ground is not permeable enough, would be to use a small-bore sewer system connected to a septic tank. The sewers only receive the liquid fraction of the household water, since the solids settle in the septic tank, and transport it to the sewage treatment plants. Unlike conventional sewers the small-bore sewers; need less water as the solids are not transported, can be laid at shallow depths and require a smaller diameter of the pipes. The treatment requirements are reduced as well since the solids are left out.

11.1.5 Subsurface flow wetland

Constructed wetlands provide a natural way to treat waste water in an artificially built environment. Wetlands consist of fields in which the water is purified by aquatic plants. The ground in combination with the plants purifies the water by filtration and biological processes. Wetlands are built out of mostly natural resources and the plants contribute to a greener environment. The only power source is the sun, which makes it very energy efficient. The purpose of constructed wetlands is to remove harmful substances and bacteria from waste water, which are not suitable to release into the nature.

Figure 26 Subsurface constructed wetland appearance above ground level (Rozema, 2007)

There are two different ways of constructing a subsurface wetland:

- Subsurface flow vertically (SSF_V) where water flows vertically through the wetland
- Subsurface flow horizontally (SSF_H) where water flows horizontally through the wetland (Scholz & Lee, 2005)

Components needed when constructing a wetland:

- Low permeability carpet if ground conditions are not suitable
- Piping to infiltrate the water into the ground
- Pump to provide an inflow into the wetland
- Septic tank
- Gravel and sand
- Plants

Subsurface flow vertically

SSF_V wetlands need inflow control since the soil needs periods of rest to be fully functional in order to grow plants in. There should be an inflow of 3 - 4 days with contaminated water into the field; the field should then rest about a week. Rest periods are critical to the plants, during these periods mineralization of total suspended solids and maintenance of aerobic conditions occurs. These processes are important for the survival of the plants. The inflow is through pipes laid out in the top layer of the wetland (Figure 27); the water then pass down through the soil to a layer of gravel, which leads it away to the recipient. This wetland type has some similes to the slow sand filtration, the water passes through an organic soil where a chemical and biological process occurs. This is an effective way of cleaning the brown water after it has been kept in a septic tank for some time. There are some issues with clogging in the infiltration pips that can occur if not properly placed out with enough gravel around them to keep organic material away. (Fujita research, 2008)

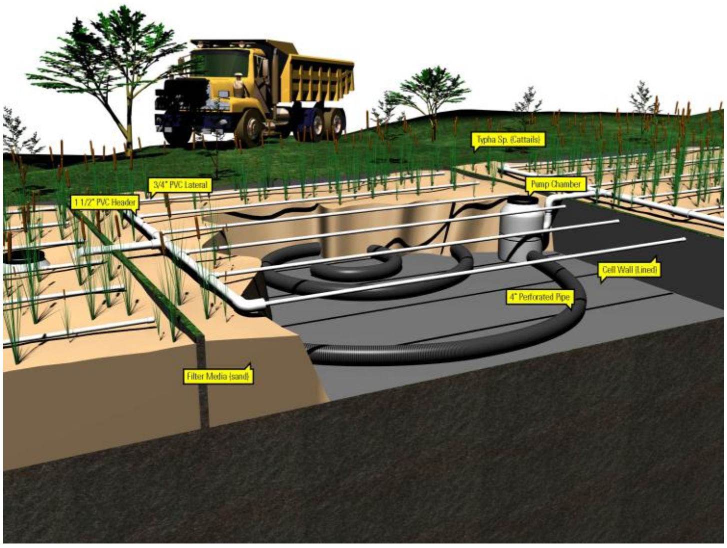

Figure 27 Principle and included components for subsurface wetland with vertical flow (Brown and Caldwell, 2012)

Subsurface flow horizontally

SSF_H wetlands do not need any resting days and therefore does not need that much attention to control the flow compared to the SSF_V system. This wetland is not as good at purifying the water from biological substances as the SSF_V. It is important that the water flows through the whole wetland, which enables the plants to decontaminate as much hazardous substances as possible. To avoid flooded wetlands, expertise is needed to manage the inflow when heavy precipitation is expected. The only situation where flooding is wanted is when the field is newly planted. (EPA, 2009)

Construction details

All constructed wetlands require a septic tank, which keeps the water for some time to kill bacteria. This will not contribute to any additional cost specific for the wetlands when the most waste water solutions demands one.

The soil in a wetland should be designed to satisfy the plants; the key is to provide the plants with a good opportunity to develop a large root system. To accommodate this, the soil consists of different layers. Directly on the ground there should be a protective layer with low permeability, above this layer there should be a thicker layer of coarse gravel where water should be transported and absorbed by the roots. (Scholz & Lee, 2005) The top layer is recommended to consist of organic material, which stabilizes and makes it easier for the plants to grow at an early stage. It also contributes to the cleaning process by consuming oxygen that creates an anoxic environment beneath the soil, which is required in some treatment processes.

Ground conditions are a vital component when building a wetland; dense soil or low permeability carpet underneath the wetland is required to prevent the contaminated water to penetrate into the ground water. This is also to make sure that the root system is in contact with the soaked soils, which is fundamental in order to clean the water. This is required if there is no natural clay layer with low permeability in the investigated ground. (EPA, 2009)

The plants are chosen to fit the environment and the waste water that is being treated. Plantation of crops in the wetland is not encouraged due to high contents of contaminations and bacteria. The plants function should be concentrated on reducing the bacteria transported through the wetland. The water treated by the wetland could then be of better use for irrigation of crops or grass. If the treated water is being used for crop irrigation the amount of bacteria per 100 ml should be checked constantly to make sure no contaminated crops are growing. (Blumenthal, Duncan Mara, Peasey, Ruiz-Palacios, & Stott, 2000)

Plants used can vary a lot around the world; the most commonly used plant is Phragmites. However, there are several different plants that can be used: Trifolium pratense, T. latifolia and P. australis, which all have different abilities to reduce contaminations in waste water. The choice of plants is not essential in the construction of a wetland; the important issue is to find a plant that will thrive in the wetland at the given location, which produces a vast root system. (Calheiros, Rangel, & Castro, 2009)

Cleaning process

The wetlands cleaning process depends on which method that is being used. The SSF_V wetlands require the least space, with a need of 2-5 m^2 of wetland per person. Using the horizontal flow wetland, you need an area of 4-8 m^2 per person which will make a major impact when the land is costly. Depending on where households are being built the severity of the construction differs largely. Wetlands are suitable to be built on flat surfaces where water flows slowly through the system. (Lehr, Lehr, & Keeley, 2005)

There are several risks that can affect a constructed wetland. The main risks are peak flows and mosquitos carrying diseases. Peak flow in combination with high concentration of organic matter can result in clogging. For example, when flooding due to high precipitation, loose materials can clog the gravel or the pipes in the wetland. Clogging can be prevented with good planning and building performance. The problem with mosquitos has caused dropped faith in constructed wetlands around the world, this because of the cost for treatment of patients with diseases carried by mosquitos. Building a SSF wetland eliminates the risks of diseases caused by mosquitos. (Rousseau, Vann, Story, & Lesage, 2006)

Waste water consists of several contaminants that that should not be released into the nature. It is important that the released water does not endanger future water sources, and that it is not detrimental to persons residing in the area. The listed contaminants are the main pollutants that are being released into domestic waste water.

Pathogens
The SSF wetlands purify the water through filtration, which is an effective method against pathogens. Filtration can in many cases be a cause of clogging, which is one of the main issues with SSF wetlands. This makes it important to make sure the water is free from larger particles before letting the waste water in. Due to increased exposure of waste water to the rhizosphere[6], there is an increase of biological activity caused, which treats the water more efficiently. Case studies have been made and the conclusion is that a SSF wetland can decrease the fecal bacteria of the waste water with 90 – 99 percent. (Hill, 2003)

Heavy metals
Removing of metals is mainly done by filtration through the soil. The plants root system improves filtration by making the soil more compact. The roots of the aquatic plants are able to take up the metals Cu and Zn and the total reduction is estimated to 80-90%. It is though hard to remove many of the other common metals in waste water, which is a disadvantage of the wetlands. (Yeh, Chou, & Pan, 2009)

Nutrients
Nutrients are preferably removed in an anaerobic environment, which can be found in the sediments of a constructed wetland. There is a chemical process that emerges in-between the roots of the plants and the sediments. This produces N_2 gas that is released into the air. (Kim, 2009)

Organic materials
The organic materials either settle in the coarse gravel or are picked up by the root system when passing through. There have been case studies showing that up to 95 percent of the organic materials are removed from the waste water in SSF systems. (EPA, 2009)

11.2 Grease clogging

When building a new water system in a developing country, including a grease trap is an improvement for the future. Grease clogging is a problem spread worldwide in sewage

[6] Rhizosphere – Part of the ground directly affected by the roots of the plant growing there. (Hill, Vincent R, 2003)

systems as expenses for cleaning the waste water pipes are very high. There are several benefits from taking care of the grease and the waste water systems service life will be increased. There is also an opportunity to compost the content which can be spread out on plantations to increase growth as the grease contains many nutrients. (Uwe & Gupta, 1997)

Grease traps normally operate easy with gravity through separation due to different density of grease and water makes the process simple. Figure 28 illustrates a grease trap that can be installed in a household. It can be built under the sink and work for some time without any major maintenance.

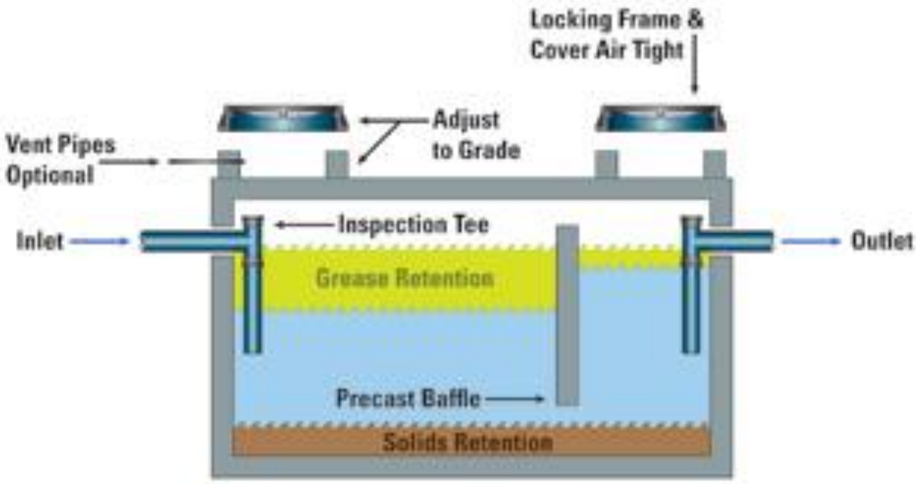

Figure 28 Simple model of a grease trap. (Gwinett County, 2012)

The cost of purchasing a grease trap is low, starting at 50 USD for a small treating system. By implementing a grease trap in every household would lower the stress on the sewage system. Grease traps need some maintenance but can often be managed by the dweller. (Uwe & Gupta, 1997)

11.3 Grey water recycling

Wastewater from households, excluding toilet water, is known as grey water and represents 50-80 percent of a households' total wastewater from e.g. sinks, showers, dishwashers and bath tubs. Grey water decomposes much faster than black water and can within 24 hours become anaerobic and later septic. (Lets Go Green, 2011) Human activity, e.g. showering and washing hands, contaminates grey water with chemical cleaning products, bacteria, pathogens and organic material. Grey water should therefore be handled carefully, but can with correct management be reused. (ECO Design, 2012)

There has been an increased demand for grey water reuse systems in the past years. Countries with water stress, e.g. Australia, have started to take advantage of grey water on a larger scale. Grey water, when processed, is used mostly for irrigation but there are projects where grey water recycling also can be used to flush toilets instead of using potable water. Australia, Japan and the US are the biggest users of grey water recycling, but other countries e.g. Sweden, Germany and Canada are also active in reuse of grey water. Countries have different motives when recycling grey water. Australia is a country with many droughts and should therefore preserve their water resources while Japan takes advantage of it to solve water problems caused by high population density. (Al-Jayyousi, Odeh R, 2003)

The benefits using grey water recycling is that up to one third of the household water usage can be spared and grey water recycling does also reduce the amount of water discharged into the sewerage system. There is several grey water recycling systems with various size and complexity, all these systems need inclusion of some sort of treatment since untreated grey water quickly deteriorates. The most common components are:

- A tank for storing water
- A pump
- A distribution system for transportation of treated water (Environment agency, 2011)

12 Analysis

The multi criteria analysis (MCA) presented in this section is based on a hypothetic housing cooperative. The structure of the cooperative, compiled for this report, is based on previous projects in Bolivia and therefore it will include many similarities. The cooperative is composed by 50 families, each with an average of six family members. There is a mutual ownership among the cooperative members which makes them all included in the development of the cooperative. During the building process, members are educated in craftsmanship in order to build their houses themselves as well as obtaining the right knowledge for future maintenance.

12.1 Criteria

Since the analysis is based on an MCA, several parameters have to be thoroughly selected in order to compare different water supply systems. Criteria in this section are based on the content in chapter 7 with some modifications in accordance with the hypothetic cooperative outside Cochabamba. These criteria have a common sustainability approach, which is reflected throughout the report; this will be of great importance in the MCA weighting. A criterion that is being excluded in the MCA is *acceptance,* even though it is listed by the UN in section 7. If acceptance were to be a criterion in the MCA, grading could only be based on speculations since there has been no case study, and hence it would not present a realistic or accurate result.

Availability and reliability

It is of great importance that sufficient amounts of water are available to provide the cooperative. The solution should consist of one main water supply system, potentially with some secondary back-up system ensuring constant water access. It is essential that the fresh water source is not in risk of over-extraction.

Distribution and technological aspects

Water distribution should rely on a pipe-network, avoiding tank trucks and single point sources. This solution is sustainable regarding financial and environmental aspects; besides, it is the most convenient solution for the consumers on long duration. Each water supply system is supposed to cover a limited household cooperative. Water towers or pressure tanks should be used when necessary to achieve enough pressure to enable distribution by pipe-network.

Economy

Since poverty is widely spread in the outskirts of Cochabamba; the major problem is to finance the establishment of a sustainable water and sewage system. Therefore, a financial plan has to be thoroughly designed in order to make it affordable in the long run. Financial means are needed both in the developing stage, during installation, for maintenance and operational costs. The locals have to be confident that the financial plan does not involve profit motives from external parties or risk for corruption. The chosen solution should be the most inexpensive alternative, but still match the demands on safety, reliability, sustainability and accessibility.

Future potential
Water demands can be expected to rise in the future, and the smaller systems may be expanded or interconnected to one major network. The overwhelming rate of urbanization puts pressure on the establishment of new water supply systems, therefore requiring it to be adaptable for further development.

Governance
In order to preclude repeated corruption it is important that the financiers of this project consist of either non-governmental organizations or the villagers themselves. Preferably, by the villagers in order to further diminish the occurrence of bribery or improper financial measures.

Legal and property rights should not be governed by any politically bounded organization to ensure avoidance of potential mistrust among the people. However, it is of great importance to clarify all the legal responsibilities to prevent future disagreements or conflicts. The most logic way to solve the ownership problem would be to own the facility as a cooperative. Hence the cooperative is also responsible for maintenance and operating of the water supply system.

Maintenance
Maintenance is an important factor in order to make the system sustainable and reliable. From an economical point of view, villagers should be the ones responsible for maintenance and operating of the system. However, this solution requires knowledge as well as responsibility among the inhabitants. Their participation is therefore of great importance throughout the entire process to ensure constant learning, but also to enhance the sense of ownership. At a certain point the locals should possess the knowledge and responsibility to maintain the water supply system on their own, which is the final aim.

The maintenance has to be equally distributed among the inhabitants with regard given to ethical and social aspects, such as division of labor between men and women, and be consistent with the community's prevailing social structure.

Quality
The water shall, after purification, satisfy the requirements specified by the UN Human Rights on drinking water standards. Sufficient water quality demands the water to be free from e.g. pathogens, parasites, heavy metals, organic particles or any other health-risking substance.

12.2 Multi criteria analysis
The MCA includes seven criteria which have been selected from section 12.1 due to their relevance in the evaluation of the techniques. All criteria in the MCA are of great importance but in comparison to each other they have been given different weights on a scale from 1 to 3, where 3 makes the criteria very important and 1 less important. The MCA is used for grading all different techniques to evaluate which technique is the most appropriate. The techniques are being graded based upon the seven criteria on a scale

from 1 to 5, where 5 is the highest score and 1 is the lowest. All techniques will then get a separate total score that will be evaluated and compared among each other.

The first criterion is a*vailability* which was weighted 3. This criterion got the highest grading because of the importance of access to the specific source e.g. water and sunlight. If availability is non-existent, the techniques will be of no use.

The second criterion is *economy* which was weighted 3. This criterion also got the highest grading due to the financial situation for the cooperative members. The members are mostly low-income people, so a very expensive technique would be challenging to implement.
The third criterion is *environmental influence* which was weighted 2. The environment has not been the main focus throughout the report but it still needs to be considered in order to present a sustainable system.

The fourth criterion is *future potential* which was weighted 1. This criterion got the lowest grading in comparison with the other criteria since there are no present plans of expanding the cooperatives in the near future. Future potential is indeed of great relevance, but the aim is rather to build a cooperative to improve today's standards and make it future sustainable.

The fifth criterion is *maintenance* which was weighted 2. The maintenance needs to be fairly simple for the cooperative members since they are responsible for managing and supervising the system. It would be possible to hire an expert occasionally for more complex problems and maintenance.

The sixth criterion is *reliability* which was weighted 2. Reliability is of considerable relevance when different techniques are evaluated. For instance, without sunlight the solar disinfection will not work very effectively. The cooperatives can still work with shorter interruptions even if the reliability at times becomes unreliable.

The seventh criterion is *quality* which was weighted 2. High quality is requested by the members of the cooperatives. Regarding quality, demands are put so that the water suffices WHO drinking water standards. Some deficits concerning taste, color and turbidity can be allowed as long as it does not imply any health risk.

12.2.1 Water extraction

In this section, grading of the different water extraction solutions will be presented.

Table 1 Multi criteria analysis of water extraction

MCA - Water extraction

Criteria	Weight	Ground water				Surface water		Rainwater
	1-3	*Sub-surface dam*	*Spring protection*	*Drilled well*	*Dug well*	*River water*	*Lake water*	*Rooftop harvesting*
Availability	3	2	1	4	3	1	1	3
Economy	3	3	4	2	3	4	3	5
Environmental influence	2	4	5	3	3	3	4	5
Future potential	1	2	3	4	4	2	1	4
Maintenance	2	2	4	3	3	3	3	4
Quality	2	2	3	5	2	1	1	3
Reliability	2	3	3	5	4	2	1	1
	TOTAL	**39**	**48**	**54**	**46**	**35**	**31**	**54**

Sub-surface dam - Not likely to exist in a larger extent and is highly dependent on surface water amount and quality, hence it can practically be out-ruled.

Spring protection - Would have been superior in quality and for economic reasons if the conditions would support it, although the geology is a limiting factor in this case. If it would exist, the water is likely to originate from shallow aquifers and therefore be of poor quality.

Drilled well - Sufficient ground water resources of high quality are available in the area, though they are located relatively deep and require high costs for drilling and pumping. As long as water extraction in each hole is kept on a fair level, there should be no risk of decreasing the ground water level. Future potential is high; however, more extraction would require further drilling. Maintenance work involves some general monitoring of equipment.

Dug well - In general the same premises as for drilled wells but some materials are impenetrable, besides well depth is more limited and the ground water quality in the shallow aquifers are generally lower at the site. In many cases this would be a way to lower costs, but since deeper wells are required, dug wells are ineligible.

River water - The only available river is Rio Rocha which is highly contaminated and thereby excluded. Another option would be to use the Misicuni River as water source. That might be possible but would involve a million-dollar-project and can therefore be out-ruled.

Lake water - There are no lakes of sufficient size and water quality in the area.

Rooftop water harvesting - A simple and minimal-cost solution that would provide free water of fair quality. However, it does not work as a complete water supply solution due to the irregularity of precipitation. It can preferably be used as a complementary source. Rainwater is a sustainable water source with a low environmental impact but the occurrence is highly dependent on the season.

12.2.2 Water treatment

In this section, grading of the different disinfection solutions will be presented. Water treatment works and slow sand filtration were excluded from the MCA since these techniques are considered to be acknowledged total solutions and thereby incomparable to the other complementary solutions.

Table 2 Multi criteria analysis of water treatment

MCA - Water treatment

	Weight	Disinfection		
	1-3	*Chlorination*	*Solar disinfection*	*Boiling disinfection*
Criteria				
Availability	3	4	4	4
Economy	3	4	5	3
Environmental influence	2	4	5	3
Future potential	1	3	3	2
Maintenance	2	5	5	3
Quality	2	4	3	4
Reliability	2	4	3	5
	TOTAL	**61**	**62**	**53**

Solar disinfection - Widely used treatment method that provides acceptable water quality at a minimal cost. Basically, it only requires re-usable plastic bottles and natural sunlight but is thereby restricted to household level. It is very easily maintained and maneuvered but is however dependent on the climate.

Boiling disinfection - Consumes large amounts of fuel in order to heat the water but provides water at very good quality. The fuel is in some areas hard to attain and prices vary accordingly. Relatively easy to maintain and can be used at any time but exposes the user to a risk of getting burned from the water.

Chlorination - Chlorine is usually accessible all year round at a low price and provides water at a very good quality. Contributes to minimal environmental impact but is more likely to be part of a larger treatment process than being further developed as a single technique. Very easily maintained and maneuvered.

12.2.3 Distribution

The water distribution system is purposed to provide water to each household in the cooperative, which is likely to be requested by the dwellers. A piped system connected to the water source is assumed to be the most feasible solution in this case. The lack of different alternatives excludes the possibility to develop an MCA on this field.

Hot water production is another probable demand by the people, storage water heaters and solar heating are two models to provide this. Storage water heaters would be preferred in the households, where a constant access is desired to an acceptable price. Solar heaters could be used as a complementary solution.

12.2.4 Sanitation

In this section, grading of the different sanitation solutions will be presented.

Table 3 Multi criteria analysis of sanitation systems

MCA - Sanitation

Criteria	Weight 1-3	*Piped system Treatment works*	*Septic tank Small-bore sewerage Treatment works / Sludge treatment*	*Septic tank Soakaway / Sludge treatment*	*Conservancy tank Treatment works*	*Septic tank Constructed wetland / Sludge treatment*
Availability	3	3	3	3	3	3
Economy	3	1	2	4	3	3
Environmental influence	2	5	4	3	3	3
Future potential	1	5	4	2	3	4
Maintenance	2	1	2	4	3	4
Quality	2	5	4	4	3	4
Reliability	2	4	4	2	4	3
	TOTAL	47	47	49	47	50

Piped system – Treatment works - Providing superior sanitation and distribution of both solid and liquid sewage at a high cost. A coherent system contributing to low environmental influence which is future adaptable to meet higher demands. Based on industrialized country standards this system demands substantial workforce to operate and maintain. Pipe fractures are complicated and inconvenient to repair.

Septic tank – Small-bore sewerage – Treatment Works/Sludge Treatment - Fair solution where costs are limited by using a low-cost pipe-system for distributing liquids, while solid waste is de-sludged. All waste is processed to minimize environmental influence, making the solution sustainable for the future. The primary areas of maintenance are de-sludging, plumbing, pipe-cleaning and waste treatment.

Septic Tank – Soakaway/Sludge Treatment - Less expensive solution which still provides adequate sewage treatment by separating solids from liquids. Releasing fecal bacteria into the ground does however involve a certain risk of ground water contamination. The system in general is feasible for small-scale usage, but is likely to have negative environmental impact if used in more densely populated areas and might thereby not be a sustainable solution. No significant work required for maintenance except for de-sludging and no considerable risk for malfunction. However, a certain area of land and permeable soil is required.

Conservancy tank – Treatment Works – This solution is based on the same principles as the piped system with the exception that the sewage is transported by trucks instead of pipes. Since the fluids are not separated from the solids, the de-sludging occurs more frequent; resulting in increased maintenance costs and emissions due to transports. This solution does though provide a possibility of replacing the conservancy tank and transportations with direct pipe network connection.

Septic Tank – Constructed Wetland/Sludge Treatment - Initial cost is relatively high in general; however, it is a long-time investment that provides a high quality liquid sewage treatment. Requires minimal maintenance and is beneficial from an environmental perspective due to natural treatment methods. Construction requires a large area of land which can increase implementation costs in densely populated areas, while operational costs are minimal.

12.3 Multi criteria results

According to the multi criteria analysis, the solutions with the highest scores are:

- **Water extraction** Drilled well
  Rooftop harvesting
- **Water treatment** Solar disinfection
- **Sanitation** Septic tank, constructed wetland/sludge treatment

The solutions with the lowest scores are:

- **Water extraction** Lake water
- **Water treatment** Boiling disinfection
- **Sanitation** Piped system, treatment works
  Septic tank, small-bore sewerage, treatment works/sludge treatment
  Conservancy tank, treatment works

13 Discussion

MCA Result

The multi criteria analysis (MCA) generated drilled wells and rooftop water harvesting as best sources of fresh water, which was relatively expected in the Cochabamba situation. Surface water was practically out-ruled relatively early in the project, leaving ground water as a primary target for water extraction. Drilled well intuitively seems like the most proper solution for extracting ground water in this case and even though there are alternative methods for reaching it, the high depth leaves drilled wells the most appropriate solution. In general, ground water is favorable since purification happens naturally to a large extent, besides, the vulnerability against contaminations and climate fluctuations is low. Possibilities of connecting the cooperative to an existing well should be evaluated initially in order to lower costs. Although, rooftop water harvesting does not pose a complete solution for fresh water supply, it can beneficially be used as complementary water supply system in order to minimize usage of purified water. Potential areas of usage in such cases are laundry, dish-washing and toilet flushing.

At some locations there might be a possibility to extract surface water for drinking, at present this solution is widely used worldwide even if the natural resources prevent usage of it in Cochabamba. In general, available natural resources are the main factor to consider when selecting fresh water source. Furthermore, extraction method is partly determined by natural resources and partly by economical resources. Chosen extraction method then determines, in compliance with economy, the appropriate purification method.

Concerning disinfection treatment, solar disinfection method got the highest rating closely followed by chlorination. This result was expected due to the simplicity, low cost and minimal environmental impact. On the other hand, chlorination is more advantageous for large-scale usage in treatment works. Treatment works can be constructed in different ways depending on prevailing demands and conditions. Slow sand filtration is only relevant in cases with surface water since it is just an artificial substitute to the natural process of infiltration, which has already taken place. In similarity with rooftop water harvesting, solar disinfection is most suitable for small-scale usage and thereby serves best as a supplementary disinfection method. Additionally, solar treatment might not be accepted in situations such as Cochabamba, where there is a certain desire for high standards. In this situation, a treatment works with main focus on chlorination and filtration would be most suitable since the water is extracted at a high depth. Boiling disinfection was excluded due to the high amount of energy required for heating and the difficulties in using it at a larger scale. However, boiling disinfection can be used as a back-up solution.

The scoring was very close between the solutions in the MCA for sanitation. According to the MCA, a septic tank should be included in the sanitation solution, as was the case for the combination with *septic tank, constructed wetland/sludge treatment*, which got the highest score. Neglecting economy aspects, all the evaluated combinations are possible to implement, which can be seen in the availability scoring. However, even if a piped system is technically possible to implement, it is assumed to be restricted due to economy.

Another limitation is that it requires connection to a proper treatment works within reasonable distance. Septic tanks are beneficial since the treatment process does not require access to a complete treatment plant. Although there are multiple ways of treating liquid sewage, there is a clear limitation in using septic tanks: solid waste must undergo sludge treatment. Liquid sewage can preferably be handled in constructed wetlands, though variations in topography may pose as a restriction. Soakaway might be a relevant solution in cases with less densely populated areas with sufficiently permeable soil and no risk for ground water contamination. Small-bore sewerage seems like a low-standard version of a full piped system, thus in cases where pipe implementation is necessary, it seems more suitable to make a proper complete solution initially. If mentioned solutions are not feasible, a conservancy tank can be used even though it should be seen as a last resort due to its unsustainability. Grey water recycling was not evaluated in the analysis, but could still be useful as a complementary process. Another complementary solution that should be considered using is grease traps. They are likely to simplify maintenance and extend the technical life length of the other sewage system components.

One of the reasons to the evenly distributed scoring in the treatment MCA was the correlation between different criteria, where weaknesses were countervailed by strengths in other criteria. For an example quality usually conflicts with economy. As in many cases, economy served as a key factor in this analysis. With the economy criterion excluded, the piped distribution system would have been superior. Assuming that the fictional cooperative would have involved more households, more financial means would have been available for financing a piped network.

MCA as method of analysis

There are several reasons why the MCA was chosen as method for analysis. The two main reasons are that it is easy to overview and that it is beneficial in comparison between the different solutions, analyzed from various perspectives. The layout constitutes a convenient tool for visualizing the result. The MCA presents a result of individual opinion and judgement based on different criteria and weighting. Hence the MCA is not just a way to visualize, but also works as a tool in the analysis. The model can easily be adapted due to importance of different aspects among different individuals. It is also organized to be compatible with analysis on other locations. There are some weaknesses with this concept of analysis and it is obvious that it does not work as a complete evaluation. Some of these weaknesses involve that the model can easily be manipulatively constructed to prove a point instead of generating an objective solution. Although one alternative gets the highest grade, it might not be the most proper alternative since the total score is a summary of all aspects. If one essential aspect is low in rank, the whole grading might be misleading. A limitation in using this method of analysis is that its suitability is limited to situations where there are different solutions to the exact same problem, meaning that the alternatives has to be comparable in function to each other. The results of the analysis are then purposed to be subject for critical review and discussion.

Housing cooperatives and social perspectives

Housing cooperatives constitutes a key in solving the water problems in Cochabamba since it acts as a link in-between the low-income people and high water quality. It plays a great role as it enables financial benefits to the dwellers. The limitations of financial means and the difficulty of accessing ground water make the situation in Cochabamba severe. Although fresh water can be accessed in Cochabamba, the depth of the aquifers increases the expenses remarkably.

Sustainability has been a fundamental consideration in the development of the criteria since it is essential that the systems provide more than short-term solutions. In order to secure technical sustainability, maintenance is important since repairs and routine controls are necessary. In a housing cooperative, maintenance is primarily supposed to be managed by the dwellers, why simplicity of the systems is beneficial. Structuring and organizing the work is a complicated matter and is partly excluded from this report. However, it should be exhaustively investigated in the planning process since the cooperatives rely on communion and co-ownership. The technical solutions assorted in the MCA are in general easy to maintain, which is an important future aspect. Water tariffs should be introduced to finance maintenance, operational and administrative costs. These tariffs also have a secondary purpose to regulate water consumption to prevent future overload of the system.

Acceptance is an essential factor that has been excluded to some extent during the project due to the difficulties in investigating people's desires without actually visiting the site. The content of this study is intended to be placed in its specific context of social aspects, why integration of social and technical parts is essential in order to achieve the most suitable water and sanitation system. Conclusions on whether or not the techniques for water and sanitation meet local demands are complex, although information about this would be of great importance. Information on specific costs have in similarity with acceptance been hard to access, hence, economic accountings have not been possible. Due to this, all economic considerations are made out of rough estimations, which have generated a rather uncertain result. It is technically and practically feasible to implement the solutions compiled in this report; however, further evaluations are necessary in combination with acceptability and specific costs.

Water supply in a broader perspective

Poverty, limited fresh water sources and unequal living standards have created a severe water situation in Cochabamba. Conflicts like the Water War and spread poverty in urban and peri-urban areas are as well consequences from processes in the society. Developing a new cooperative will most likely make it easier to improve the water conditions for new members. The solution with a new-built cooperative will, if properly done, contribute to better and more secure water access. This will be achieved mainly through a mutual investment of time and money and a clear working strategy.

Better water conditions will probably lead to increased consumption. This is certainly something positive since sufficient access to water is a human right. Cautiousness is of importance since increased water-consumption could have some severe impact on sustainable development if water resources are not treated properly. This puts high demands on water supply, both in terms of the amount of water and quality of water. The treatment needs to be done well in order to protect the environmental surroundings. When consumption increases, water resources in Cochabamba will deteriorate; ground water level could decrease and in turn create difficulties since water supply is based on today's levels. Increased consumption also leads to greater demands on sanitation due to the larger volumes of black and grey water. Climate changes are also factors that need to be considered, even though accurate predictions are extremely difficult to present. An expected scenario is increased average precipitation in combination with more extreme rainfalls and droughts. This could most likely affect recharge processes and conditions for rainwater harvesting.

It is not only in Cochabamba the water situation is severe. Many places around the world lack access to proper water sources and are also in need of great improvements. All throughout the world the model with housing cooperatives is a possible solution to improve the water situation. When implementing the cooperative solution, the most important work is to first define problems and specify demands. Thereafter, thoroughly examine the given conditions, possibilities and limitations concerning demographic situation of the households and regarded geographic location. The most crucial factor considering shaping the solution is economic conditions. When the people can finance the cooperative themselves, the solution becomes most favorable. Otherwise possible financiers are governments, private initiatives or NGOs, which is a more unreliable way of getting economical means. Hence, unfortunately, the money limits the construction of cooperative households and water and sanitation systems.

14 Conclusion

A *Water Solution Scheme for Cooperative Households* has been developed to work as a tool for implementation of water supply and sanitation. In the scheme, general procedures are presented chronologically in the left column while the right column presents the procedures applied on the Cochabamba case. By following the included steps properly, **a solution that is sustainable concerning the whole water cycle and its influents will be achieved in a housing cooperative.**

Water Solution Scheme for Cooperative Households		
	General Procedure	**Solution for Cochabamba**
1	**Define problems and specify demands** *Situation overview, main restrictions* and *local expectations etc.*	- The fundamental problems are poverty and water scarcity. - Create a sustainable water management system for 50 families. Proper housing, modern water standards.
2	**Examine geographic conditions, possibilities and limitations** *Natural resources, climate, hydrogeology, geography etc.*	- Steady and fair temperature, rarely drops below freezing-temperature. Cochabamba is situated in a valley surrounded by the Andes. - Adequate water quality in deep aquifers and in a distant river. - Heavily polluted surface water, contaminated shallow aquifers, low and irregular precipitation, long-lasting dry seasons.
3	**Examine demographic conditions, possibilities and limitations** *Private economy, financing possibilities, culture, health, population etc.*	- Cultural diversity, high urbanization, agriculture - Similar successful projects, positive attitude - Low-income people, low average life-length, waterborne diseases, economic segregation and difficulties in taking loans.
	The three first steps form a basis for all following steps in the planning process	
4	**Choose fresh water source** *Based on e.g. economy, available sources, quality, environment, acceptability and future potential.*	Deep aquifers are basically the only reliable fresh water source of sufficient quality and at an affordable cost.
5	**Assess fresh water contaminants**	Pathogens and organic matter (hypothetically)
6	**Determine extraction, purification and sanitation solutions corresponding to collected data**	Pumping water through drilled well in deep aquifer. Purification plant including filtration and chlorination. Distributed through piped network to households. Sewage treatment consisting of septic tank, constructed wetland and sludge treatment. Sewage distribution includes pipe connection to wetland and de-sludging truck.
7	**Determine fresh water and sewage distribution system (in accordance with step 6)**	
8	**Organize maintenance and administration**	Whole project following the concept of “help to self-help”, maintenance and administration financed by water tariffs. Construction is financed by cooperative bank loans.
9	**Structuralize financing and construction**	

The difficulty in developing water and sanitation solutions in housing cooperatives is that each specific case is unique and the influencing parameters are seemingly infinite. Examining and evaluating local conditions, possibilities and limitations turned out to be the key factor of the process and since the scheme is universally developed, it can be applied on any case worldwide.

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Appendix 1: Municipal water supply treatment

Table 1: Municipal water supply treatment

Attribute	Explanation	Treatment method
Clarity / Turbidity	Water may contain suspended or very fine dispersed particles such as silt or plant residues that cause it to be murky.	Suspended particles are removed by filtration. Fine, dispersed particles, also called colloids, pass through a normal filter. They are normally coagulated / flocculated to form larger particles (flocs) before the filter.
Colour	The colour of water can arise naturally or can be caused by pollution. Natural colour such as that found in the brown waters of the Cape is caused by plant residues and is harmless. Small amounts of iron and mangenese that occur naturally can also cause colour. Colour arising from industrial pollution may spell danger.	Natural colour can be removed by coagulation / flocculation followed by filtration. Similarly colour resulting from pollution can be removed, but careful monitoring and expert advice is needed. Iron and manganese may need aeration prior to coagulation.
Taste / Odour	Taste is affected by dissolved gases, chemicalsand residues from plant and other materials.	Aeration can be used to eliminate dissolved gases. The removal of excess salts requires advanced treatment procedures such as those discussed under desalination. Organic substances can be removed by coagulation / flocculation and filtration with absorbtion on activated carbon for really persistent substances.
Hardness	Dissolved calcium and magnesium salts in the water cause hardness. Hardness increases the amount of soap needed to give lather and results in deposits in geysers and kettles.	Softening processes should be used such as adding sodium carbonate or using ion exchangers.
Changing the Chemical Content	As discussed under colour, taste/odour and hardness, water can dissolve most substances. The natural inorganic salts, when seen as a group, are normally referred to as the TDS of the water. High concentrations of these salts make the water brakish, and are removed through desalination. Pollution arising from human activities such as mining, industry and agriculture may give rise to certain harmful chemicals in the water that need to be removed. Arsenic, fluoride and nitrates are naturally occurring substances that may require removal when present in high concentrations.	Desalination processes such a reverse osmosis, electrodialysis, distillation and ion exchanges, as discussed below, are suitable for removing TDS. The removal of specific toxic substances arising from natural causes or pollution needs special advice.
Reducing the Bacterial Content of Water	Most surface waters and some ground-water contain bacteria, some of which may be harmful to human health.	Bacteria are removed by the disinfection processes that are discussed below.

Treatment processes include:

Chemical Stabilisation

Chemical stabilisation is achieved through the addition of chemicals such as lime or carbon dioxide. This is used to protect pipelines and fixtures from chemical scale (hard deposits on the inside of pipes, kettles etc.) and corrosion.

Coagulation/Flocculation

Coagulation can be used to improve the chemical quality of water. Further, it can be used to treat micro-organisms and water with a high turbidity (high TDS). The coagulant causes the fine particles to form larger particles (flocs) which then settle to the bottom of the tank and can be removed.

Defluoridation

Fluoride can be removed from water using activated alumina or bone char and ion exchange. A high intake of fluoride can cause tooth staining and hardening of the bones making them brittle.

Desalination

Desalination reduces the level of dissolved solids in water. This is important in areas where borehole waters have a high salinity (brackish water) and where the possibility of finding other affordable sources of water is low. The processes that can be used for desalination include ion exchange, electrodialysis, reverse osmosis, distillation and chemical precipitation.

Distillation

Energy is applied to the brackish water (high total dissolved solids) to form water vapour (leaving dissolved salts behind) and the vapour is condensed to form pure water with low total dissolved solids. Solar energy can be used to produce water vapour and this process is known as solar distillation or solar still.

Electrodialysis

Electrodialysis uses membrane technology, but the driving force in this case is electrical potential. Water passes through electrically charged membrane pairs. Dissolved solids are then removed from the water. This process can be used to treat water with high concentrations of TDS, chloride, potassium, sodium and sulphate.

Filtration

Water is passed through a filter to improve quality. Simple, inexpensive systems can reduce turbidity. More sophisticated systems can also remove some contaminants. The filtration method may not remove all micro-organisms, so disinfection is required after filtration to ensure that the water is safe for drinking.

Ion Exchange

Ion exchange is achieved using an ion exchange resin. The undesirable cat-ions or anions in the water are exchanged for ions found within the resin as the water passes through it. The resins have a limited capacity to exchange ions and, when this is exhausted, the resin must be regenerated using a brine solution. The ion exchange process can be used to soften hard water, for desalination (reduction of TDS), and for the chemical treatment of water i.e. for the removal of fluoride, nitrate, iron etc. The ion exchange process can also be used at a household level. This however can be very expensive.

Mixed Oxidant Gases Generated On Site for Disinfection (MOGGOD)

The MOGGOD process uses normal table salt to manufacture a chlorine equivalent. An electric current is passed through the salt. The chlorine that results is then used to disinfect the water supply.

Nitrate Removal

Nitrate can be removed from water using ion exchange, reverse osmosis and biological reduction (denitrification). The presence of high levels of nitrate in water can be of risk to babies.

Ozone Treatment

Ozone is produced on site by passing a current of dry filtered air between two electrodes subjected to an alternating voltage. The ozone acts as a disinfectant and an oxidant that reduces the contents of iron, manganese and lead. It can also eliminate taste and odour problems.

Reverse Osmosis

Fresher water can be produced by forcing water with a high content of total dissolved solids, under pressure, through a special membrane. The dissolved solids are rejected by the membrane and they stay behind, while pure water goes through the membrane. Reverse osmosis can be used for the treatment of water with high concentrations of nitrate / nitrite, potassium, sodium, sulphate, chloride, fluoride and TDS.

Sedimentation

Sedimentation is a process where water is allowed to stand for a period of time. Suspended solids settle at the bottom of the container through gravity.

Treatment of Encrustation / Biofouling of Boreholes

If borehole water is tinted brown and smells of rotten eggs it is an indication that it has been infected by either metal encrustation or bacteria, or both. Treatment can begin by using mechanical tools to clean easy-to-reach places. This can be followed by chemical treatment that uses acids to dissolve precipitations. The well should then be cleaned out by jetting, airlifting or bailing, followed by the addition of a disinfectant such as chlorine.

UV Treatment

An Ultra-Violet (UV) light is used to disinfect water. UV lamps can be placed in water pipes, ensuring that the water passing through these pipes receive a fixed average dose. Lamps can also be mounted above shallow tanks through which the water is passed.

References:

- Department of Water Affairs and Forestry have published the South African Water Quality Guidelines (1996) for both Fresh and Coastal Marine Waters.
  See www.dwaf.gov.za or go to your nearest regional DWAF office.

- The following five volumes on Water Quality are available from the Water Research Commission:
  - Quality of Domestic Water Supplies
  - Volume 1: Assessment Guide WRC no. TT 101/98
  - Volume 2: Sampling Guide WRC no. TT 117/99
  - Volume 3: Analysis Guide WRC no. TT 129/00
  - Volume 4: Treatment Guide WRC no. TT181/02
  - Volume 5: Management Guide WRC no. TT 162/01