CHALMERS

Sustainable and affordable water and wastewater solutions for a low-income housing cooperative in Cochabamba, Bolivia

Master of Science Thesis in the Master's Programme Industrial Ecology

Alvar Palm

Department of Civil and Environmental Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2010

Master's Thesis 2010:139

Sustainable and affordable water and wastewater solutions for a low-income housing cooperative in Cochabamba, Bolivia

Alvar Palm

Master degree project (30 hp)
Department of Civil and Environmental Engineering
Division of Water Environment Technology
Chalmers University of Technology
Göteborg, Sweden, September 2010
Report No. 2010:139

Supervisors:

Sébastien Rauch
Water Environment Technology
Chalmers University of Technology
Göteborg
Sweden

Graciela Landaeta
Head of board
Procasha Foundation
Cochabamba
Bolivia

Abstract

In this master thesis, options for water supply and wastewater treatment for a Bolivian housing cooperative of 26 households are identified and assessed with a focus on social, economic and environmental sustainability. The cooperative owns a lot in the municipality of Sipe Sipe, close to Cochabamba, Bolivia, where construction work is currently going on, the cooperativists building their own dwellings under guidance from professional construction workers and architects. The thesis contains four main parts:

Water Resources
Available water resources and the extent to which they can be utilized were determined on site. These include surface water, subterranean water and rainwater. The assessment of these resources was based on availability (flows, seasonal variability and storage possibility), water quality (for both drinking and household use) and costs.

Water systems
Options for the production and distribution of water were assessed with a focus on low-cost options and water preservation, and production methods based on available water resources were proposed.

Wastewater systems
Options for wastewater handling were studied, including possibilities to recycle water for groundwater recharge or irrigation. Artificial wetlands have successfully been used for wastewater treatment in the region and a feasibility study was performed. Options for toilets were also studied.

Risks
Risks were determined for suitable water supplies, and cheap methods to guarantee water quality (especially for drinking water) has been suggested. Potential sources of contamination in the area were determined.

The project was performed under the guidance of The Procasha Foundation, which is leading the development of this and other cooperative housing projects in the area. The options investigated in this project were discussed with the technical team of Procasha and the cooperativists, to ensure that they are acceptable and will be used.

It was found that the local groundwater should be used for water supply, and that the best option to exploit this resource probably is to connect to an existing nearby well. It is recommended that solar water heating systems be used to provide hot water, and that dry toilets be chosen for the dwelling houses. Water efficient household equipment should be installed in kitchens and bathrooms. UV-disinfection and solar pasteurization offer cheap and energy-saving methods for securing that drinking-water is free of pathogens.

Key words: Bolivia, Cochabamba, housing cooperative, wastewater treatment, potable water, constructed wetlands, water reuse, dry toilets.

Resumen

En esta tesis, opciones para el abastecimiento de agua potable y tratamiento de aguas residuales, para una cooperativa de viviendas boliviana de 26 hogares, son identificadas y evaluadas enfocando su sostenibilidad social, economica y medio-ambiental. Las casas de la cooperativa actualmente están bajo construcción en el municipio de Sipe Sipe cerca de Cochabamba, Bolivia. Los cooperativistas están trabajando con la edificación bajo dirección de profesionales. La tesis consiste de cuatro partes:

Recursos de agua
Los recursos disponibles de agua, y el alcance a que pueden ser explotados, fueron determinados. Estos incluyen aguas superficiales, aguas subterráneas, y aguas pluviales. La evaluación de esos recursos fue basada en su disponibilidad (flujos, variablidad temporal, y posibilidad de almacenimiento), calidad del agua, y costos.

Sistemas de agua potable
Opciones para la producción y distribución del agua fueron determinadas enfocando soluciones de costo bajo y eficiencia hídrica, y métodos de producción basados en los recursos de agua disponibles fueron propuestos.

Sistemas de aguas residuales
Opciones para el tratamiento de aguas residuales fueron investigadas, incluyendo posibilidades de reciclar el agua para regar. Pantanos artificiales han sido utilizados con éxito en la región, y un estudio de viabilidad fue realizado. Opciones para inodoros fueron investigadas.

Riesgos
Riesgos fueron determinados, y métodos baratos para garantizar la calidad del agua fueron propuestos. Fuentes potenciales de contaminación de los recursos de agua fueron determinadas.

El proyecto fue realizado bajo la dirección de la Fundación Procasha, que está manejando el desarrollo de este proyecto de viviendas cooperativas, igual que otros en el area. Las opciones investigadas en el proyecto fueron discutidos con el equipo técnico de Procasha y los cooperativistas para garantizar que sean aceptables y serán utilizadas.

El agua subterránea se debe utilizar, y la mejor manera de explotarla probablemente sería afiliarse a un pozo cercano del lote de COVIVIR. Calefones solares deben ser utilizados para calentar el agua. Baños secos deben ser construidos para las viviendas para evitar gastos de agua y reusar nutrientes. Equipamiento eficaz respecto al agua debe instalarse en las cocinas y baños. Existen métodos de bajo consumo de energía para desinfectar al agua, utilizando la irradiación solar.

Palabras clave: Bolivia, Cochabamba, cooperativa de viviendas, tratamiento de aguas residuals, agua potable, pantanos artificiales, reuso de agua, baños secos.

Sammanfattning

I denna masteruppsats identifieras och utvärderas olika alternativ för vattenförsörjning och avloppsvattenshantering för ett bolivianskt bostadskooperativ om 26 hushåll, med fokus på social, ekonomisk och miljömässig hållbarhet. Kooperativets bostäder är för närvarande under uppbyggnad av medlemmarna själva, under professionell ledning, i kommunen Sipe Sipe nära staden Cochabamba i Bolivia. Uppsatsen innehåller fyra huvuddelar:

Vattenresurser
Vilka vattenresurser som finns tillgängliga, och i vilken utsträckning dessa kan användas, undersöktes på plats. Resurserna inkluderar yt-, grund- och regnvatten. Utvärderingen av dessa resurser baserades på tillgänglighet (flöden, variation mellan årstider, samt lagringsmöjligheter), vattenkvalitet och kostnader.

Vattensystem
Alternativ för produktion och distribution av vatten utvärderades med fokus på lågkostnads- och vattensparande utrustning med i övrigt låg miljöpåverkan, och metoder baserade på tillgängliga vattenresurser rekommenderades.

Avloppsvattensystem
Alternativ för avloppsvattenshantering studerades, inklusive möjligheter till återanvändning av vatten för bevattning. Anlagda våtmarker har framgångsrikt använts för att behandla avloppsvatten i området, och en förstudie genomfördes. Alternativ för toaletter studerades.

Risker
Risker utreddes för de passande alternativ som diskuterats, och billiga metoder för att garantera vattenkvalitet föreslogs. Möjliga källor till förorening i området kartlades.

Projektet har utförts under vägledning av stiftelsen Procasha, som leder utvecklingen av detta och andra bostadskooperativ i området. De alternativ som undersökts och föreslagits har diskuterats med Procashas medarbetare och med kooperativets medlemmar för att säkerställa att de är acceptabla och kommer att användas.

Det lokala grundvattnet bör användas för vattenförsörjning, och det bästa sättet att komma åt detta är troligtvis att ansluta sig till en närbelägen brunn mot en engångsavgift om 500 US$ per hushåll. Solpaneler bör användas för uppvärmning av vatten. Användning av torrtoaletter rekommenderas starkt för bostadshusen, liksom installation av vattensnål utrustning i kök och badrum. Enkla metoder för att desinficera vatten med hjälp av solens strålning finns och bör väljas framför kokning av vatten på spis, för att undvika onödig förbrukning av energi.

Nyckelord: Bolivia, Cochabamba, bostadskooperativ, avloppsvattenshantering, dricksvatten, anlagda våtmarker, återanvändning av vatten, torrtoaletter.

Preface

This master thesis was carried out with financial support from the Swedish International Development Cooperation Agency (SIDA) through the MFS scholarship, which has the purpose of giving students an opportunity to perform field studies in a developing country for their bachelor or master projects. The project was carried out in cooperation with the Procasha Foundation, located in Cochabamba, Bolivia.

I would like to thank my supervisors, namely Sébastien Rauch at Chalmers University of Technology, and Graciela Landaeta, founder of the Procasha foundation. I would also like to thank the Procasha staff for their invaluable help with practicalities and information, and for making me feel welcome during my stay in Cochabamba. A special thanks to Hernán Aranda who, besides helping me with all kinds of practicalities related to my project, lent me money when I had my wallet stolen, and stayed several hours at the hospital emergency ward in the middle of the night as I was treated for food poisoning.

Finally, I would like to send a great thank you to all the people who contributed information to my project by generously offering me a moment of their time answering my questions, and to the cooperativists of COVIVIR for good company during my fieldwork on the construction site. Thank you all!

Göteborg 2010-09-05
Alvar Palm

Contents

Glossary:

Bolivianos: The currency of Bolivia. One boliviano equals about 0.1 €.

Centro comunitario: The common building of the cooperative, used for reunions, taking care of children during day-time, and other purposes.

COVIVIR: The name of the housing cooperative.

Diamicton: A very poorly sorted sediment, i.e. soils constituted by gravels and sands as well as smaller granular materials such as silt and clay.

OTB (organisación territorial de base): A kind of organization introduced by the 1994 Law of Popular Participation (Ley de Participación Popular), that encompasses a certain amount of land as well as its dwellers. Operated by local people, the OTBs have as their duty to negotiate with the authorities, representing its members (Landaeta, 2004). Every Bolivian is a member of an OTB (Lema et al. 2001).

Procasha: A foundation without profit interests located in Cochabamba, Bolivia, dedicated to improving residential conditions of the low-income segments of the local population.

Semapa: The public water company of Cochabamba.

Río Rocha: The only perennial river of the valley, which flows through the city Cochabamba, and further downstream through Sipe Sipe. The river is heavily contaminated.

Sipe Sipe: The municipality where the cooperative COVIVIR is to be situated.

1. Introduction

1.1 Bolivia

Bolivia, the poorest country of South America, finds itself landlocked with great portions of its territory located on high elevations in the Andean mountains. Its climate varies considerably from the chilly Altiplano (Spanish for *highlands*) in the west to the tropical lowlands of the east.

Poverty is a severe problem. During the beginnings of this century, 65% of the country's population was subsisting below the national poverty line (UNDP, 2009). As is often the situation in developing countries, access to housing and land is an important issue, aggravated over the past decades by migration to cities and urban poverty.

1.2 Cochabamba and the Central Valley of Cochabamba

The Central Valley of Cochabamba is home to the city Cochabamba, which with its metropolitan population of more than one million is the third largest city of Bolivia. The population of the area increases rapidly, mostly due to migration, which has caused increased problems of violence and segregation (Ledo, 2009). Urban expansion over land used for agriculture leads to conflicts and decreased food security. The rapid population increase in the municipality of Cochabamba in the 1990s has decelerated, though, and in the old city center the population is decreasing; instead, people seek less expensive land in neighboring municipalities within the metropolitan area. During the period of 2001 to 2008 the mean annual population growth of the metropolitan area was about 3.9% (Ledo, 2009). The population of the valley is large not only in the urban areas, but also in the countryside, which makes the need large for potable and irrigation water (Neumann-Redlin, 2000).

The valley suffers an enjoyable temperate climate all year round with an annual mean temperature of 17.5^{o} C (Neumann-Redlin, 2000). The annual precipitation is usually about 400 to 500 mm, of which the greater part falls during the months October to April, and almost nothing during the period June to July (UDAPE).

The valley, surrounded by the mountains of the Cordillera Oriental, has a mean elevation of about 2500 meters above sea level and possesses an area of about 390 km^2 (Ledo, 2009). Originally, the valley was covered by forest (Neumann-Redlin, 2000), but nowadays most of the non-urbanized land is used for cultivation. The only perennial river of the valley, Río Rocha, which is heavily contaminated, flows through Cochabamba and exits the valley in the south west. Several intermittent rivers discharge their waters into Río Rocha during times of rainfall.

1.2.1 Housing situation

Housing deficit is severe, and illegal settlements are common, normally located in peri-urban areas which lack infrastructure for public water and sanitation services as well as social services like health care and education. According to estimations, 45-55% of urban dwellings constructed in Bolivia every year are informal (Ledo, 2009). The need for affordable housing has led to an uncontrolled growth of Cochabamba to the south, as low-density peri-urban habitat sprawls over land that is far more affordable than that in the more prosperous northern parts of the city. According to Ledo (2009), a major reason for the large economic segregation in the city is that land and property have been subjects to economic speculation. About half of the households in Cochabamba own their dwelling, while the households of the other half rent, borrow or access it in some other way. A common solution is that the dweller does the house owner personal favors in exchange for lodging, often hard manual work like construction (Ledo, 2009).

Overcrowding is large in Cochabamba, and more than half of the households lack access to potable water and public sewage systems, in numbers reaching 92.3% and 97.2% respectively in the southern area Periferia Sur, which is home to more than 26,000 households (Ledo, 2009).

1.2.2 Environmental issues

Treatment and collection of garbage, as well as wastewater treatment, are severely malfunctioning, especially in the southern parts of Cochabamba. The Kara Kara landfill, located close to the city, was implemented in 1987; according to Ledo (2009), this was done stretching the regulation without any consideration of technical norms for control and mitigation of environmental damage. This has, according to Ledo, produced an environmental disaster without equivalents in the city, as water, ground and air are polluted, threatening the health of neighboring dwellers.

Another pollution hot spot of the area is the municipal wastewater treatment plant of Cochabamba, which due to being grossly under-dimensioned emits water that has received insufficient treatment (Ledo, 2009).

1.2.3 Water situation

In Bolivia, insufficient access to water of good quality is a major cause of ill health, and Cochabamba is not an exception; severe diarrhea caused by contaminated drinking-water is common, and is the main cause of infant death. In the poor areas of Cochabamba, each family consumes about 125 liters of water per day, which is less than what one single person consumes in the richer northeastern parts (Ledo, 2009).

Only about half of the households of Cochabamba are connected to the public water system, operated by the municipal water company Semapa. The rest have to rely on other solutions, like private wells or tank trucks, both of which often bring water of dubious quality. In addition, the tank trucks are often unreliable, and the water is significantly more expensive than that of SEMAPA; often about 10% of the families' incomes goes to pay the household water (Ledo, 2009).

In the year 2000, a series of protests took place that would be known as the Water War, as thousands of people upset by raised water tariffs took to the streets. The background was that the World Bank, as a condition for approving a loan to Bolivia, had demanded that the public water company be privatized. The result was – in addition to more than 100 wounded and the death of a 17-year old boy – that the water services returned to public control (Shultz and Crane Draper, 2009).

1.3 Sipe Sipe

The municipality of Sipe Sipe, located in the south-western corner of the valley about 25 km from the Cochabamba city center, is considered a part of metropolitan Cochabamba. According to a 2001 census the municipality population at that time was 31,337 inhabitants, of which 65% lived in rural areas. The annual population growth between 1992 and 2001 was 4.85%. By tradition, the most important economic activity in the municipality is agriculture (H. Alcaldía municipal de Sipe Sipe, s. 31).

1.4 The housing cooperative COVIVIR

As a redemption to the housing problems, cooperative housing initiatives, in which members are working together to solve their housing needs, have been developed. The Bolivian foundation Procasha (Fundación de Promoción para el Cambio Socio Habitacional) is currently working to introduce the model *cooperative housing through mutual aid* in Bolivia, a model which has been used successfully in Uruguay for a number of years.

Current projects include the cooperative COVIVIR, which consists of 26 families (about 130 persons) that plan to live together in a piece of land located in the municipality of Sipe Sipe, near Cochabamba. The lot, extending over an area of 6000 m^2, has been bought with a loan from The Swedish Cooperative Centre and is owned by the cooperative. However, to be affordable, it is located beyond city limits and without access to public water and sanitation. Construction work is currently going on, the cooperativists themselves building their dwellings under guidance from professional construction workers and architects.

COVIVIR will possess three row-houses for the dwellings as well as a common building for meetings and other common activities, called *"el centro comunitario",* or *"the communitary center".* All buildings will be placed around a space that will contain access roads, parking lots, a field for ball games, and green areas (see appendix I for a plan of the housing area). The only building that had started to undergo construction when the field work was carried out was the centro comunitario.

1.5 The MFS project

Up to this point, little attention has been paid to sustainability issues when designing water and wastewater systems for the cooperatives mentioned above. For the cooperative COVIVIR, several options are potentially available for the supply and management of water and wastewater, and the project that has resulted in this thesis aimed at identifying them and assessing their applicability with a focus on environmental, social and economic sustainability. The thesis contains four main parts:

Water Resources

Available water resources and the extent to which they can be utilized were determined on site. These include surface water, subterranean water and rainwater. The assessment of these resources was based on availability (flows, seasonal variability and storage possibility), water quality (for both drinking and household use) and costs.

Water systems

Options for the production and distribution of water were assessed with a focus on low-cost options and water preservation, and production methods based on available water resources were proposed.

Wastewater systems

Options for wastewater handling were studied, including possibilities to recycle water for groundwater recharge or irrigation. Artificial wetlands have successfully been used for wastewater treatment in the region and a feasibility study was performed. Options for toilets were also studied.

Risks

Risks were determined for suitable water supplies, and cheap methods to guarantee water quality (especially for drinking water) were suggested. Potential sources of contamination in the area were determined.

The options investigated within the project were discussed with the technical team of Procasha and the cooperativists to ensure that they are acceptable and will be used.

1.5.1 Objectives

This project aims at identifying and assessing water supply and sanitation options for the housing cooperative COVIVIR in Sipe Sipe with a focus on social, economic, and environmental sustainability. Risks are also considered.

1.5.2 Methodology

Besides from literature studies, interviewing local experts on water issues has been an important way of obtaining information about local conditions and prerequisites. Practical fieldwork, such as sample-taking for laboratory investigation, and on-site testing of soil characteristics, has also contributed important information.

2. Water resources

In this chapter, the different options potentially available for water supply are described and discussed, including local surface and subterranean water, rainwater and water delivered by tank trucks. These sources differ substantially in availability, security and contamination levels. Their potential for delivering sufficient amounts of water with a satisfying quality during the course of the year is determined, and at the end of the chapter recommendations are made.

2.1 Surface water

Río Rocha, the only perennial river of the valley, passes about three kilometers from the cooperative. The river is heavily polluted, and its flow is small during large parts of the year. Throughout its path, it is a receptor for domestic and industrial wastewater that in most cases is not adequately treated, and for that reason, the river shows higher levels of bacteriological contamination the more downstream samples are taken (Maldonado et al., 1998). Many of the poultry farms located in the area emit their residues without treatment into the river (Heredia, interview 2010-04-13), and Cochabamba's overloaded municipal wastewater treatment plant, known as Alba Rancho, feeds it with insufficiently treated wastewater – in 2002 Alba Rancho received the wastewaters from 456,000 persons, although it was only dimensioned for 162,000 (Moscoso and Coronado, 2002). The waters from the rivers of the area are used mainly for irrigation (H. Alcaldía municipal de Sipe Sipe, s. 13).

Several intermittent rivers discharge their waters into Río Rocha during times of rainfall, two of them passing about 300 meters from the site of the cooperative, to the north and south respectively.

The municipal water company of Cochabamba, Semapa, is exploiting surface water at two locations in Cochabamba's mountainous surroundings – in Escalerani and Wara Wara, located about 40 and 20 km to the north of the city, respectively. There are plans to open up a third surface water catchment in the City's surrounding mountainous area (Requena, interview 2010-04-22).

2.2 Rainwater

Rainwater harvesting has been increasingly paid attention to in recent years as a mean to reduce water insecurity in areas where water supply is problematic. Water is often harvested from roofs, tarpaulins, or other watertight surfaces, and stored in a tank. Rainwater harvesting is inexpensive, and can be implemented in connection with the construction of a new building, as well as well as at existing buildings.

The water is in many cases drinkable without treatment, but could be treated through disinfection as a safety precaution (see section 3.3 for sustainable disinfection methods). Organic and inorganic contamination is generally low, even though there is a risk of the water being contaminated by air pollutions (HarvestH2o.com, 2010-06-29). There is also a risk of the water being contaminated by animals in the catchment area.

The International Rainwater Catchment Systems Association advices that for rainwater harvesting from roofs to be viable, the following requirements should be fulfilled:

- rainfall should be over 50 mm $month^{-1}$ for at least half of the year (unless other water resources are extremely scarce),
- local roofs should be made out of 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, and
- 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, 2010-06-29)

The annual precipitation in the municipality of Sipe Sipe is about 650 mm with relatively big variations within the area, due to differences in elevation. Almost all the rain falls within the rain period, October to Mars, with January being the rainiest month of the year. In the urban center of Sipe Sipe, which is located close to the cooperative and at about the same elevation, annual precipitation is about 470-500 mm, and the number of rainy days per year is usually around 60 (H. Alcaldía municipal de Sipe Sipe, s. 10).

The basic roof harvesting system consists of a tank for storing, and guttering to lead the water running off the roof into the tank. The intermittent character of rain as a direct source of water makes roof rainwater harvesting a non-ideal solution for a stand-alone water supply, and should in most cases be looked upon as a complementary system. The system, however, gives a household a good security against short-time failures of other sources (IRCSA, 2010-06-29).

2.3 Groundwater

Groundwater is the predominating source of household water in the region, and thousands of drilled and dug wells are located throughout the valley. Generally, in the central parts of the valley the flows of the wells, which are normally up to 125 m deep, reach 30 l s^{-1}, while the flows in the southern parts are lower. The waters of the more shallow aquifers generally contain appreciable amounts of calcium, magnesium and bicarbonate, and, if not polluted, are suitable for all use (Neumann-Redlin, 2000).

The groundwater around Sipe Sipe is often polluted due to a lack of regulation on wastewater cleaning (H. Alcaldía municipal de Sipe Sipe, s. 20). Studies in nearby Quillacollo together with other areas have shown that there are no significant differences in the levels of bacteriological groundwater contaminations between these areas. However, a reversed proportionality between depth and bacteriological contamination was discovered, and it was stated that the contaminations originated from infiltration from septic systems and other human activities such as animal breeding (CGIAB, 2009).

Semapa operates about 30 wells in the valley, typically with a depth of 100 to 140 meters. Normally, water is not extracted at depths smaller than about 60 meters. Extraction takes place at certain depth-intervals of the wells where the hydrogeological conditions are favorable (Requena, interview 2010-04-22). Laboratory tests have shown that the waters extracted from 27 of Semapa's wells are free from total coliforms as well as fecal coliforms (see appendix VII), but the water is still clorified to prevent effects of contamination in the distribution pipes (Requena, interview 2010-04-22). Depths and flows, along with some other characteristics of the wells, can be seen in appendix VIII. Other characteristics of the wells, soils and aquifers are not available at Semapa since this information was not transferred to the company from the companies drilling the wells. Semapa is not allowed to drill any more wells in the area, and is therefore planning to expand its surface water harvesting in the surrounding mountains from two to three catchments (Requena, interview 2010-04-22).

2.3.1 Geology and hydrogeology

During recent decades, several studies have been carried out in order to investigate the geologic and hydrogeologic situation in the Central Valley of Cochabamba. The thickness of the sedimentary layer in the valley varies from less than 100 m in the southeast to more than 1450 m in the north, and the composition of the layer varies considerably both horizontally and vertically throughout the area; thus, aquifers may show very differing properties within short distances, and open as well as confined and semi-confined aquifers are common. In the north, the sedimentary layer is constituted by coarse material like blocks and gravel, together with sand or clayey sand. Southwards, the materials gradually turn finer, and in the southern parts (particularly in the south-east) sandy mud, clayey mud and gravely mud dominate the layer (Neumann-Redlin, 2000). The cooperative COVIVIR is located in the south-western corner of the valley.

The transmissivities of the aquifers vary from more than 400 m^2 day^{-1} in the northern parts of the valley to less than 9 m^2 day^{-1} in the south. The recharge of the aquifers mainly takes place in the north of the valley through infiltration of surface water from the mountains. In the area where the cooperative’s lot is located the transmissivity is between 9 and 43 m^2 day^{-1}. Three deep wells (up to 550 meters in depth) have shown that the conductivity diminishes with increased depth due to layers of mud that restrain recharge. Because of these layers, the production capacities of deep wells only slightly exceed those of wells that exploit more shallow aquifers. Also, water quality diminishes at large depths (Neumann-Redlin, 2000).

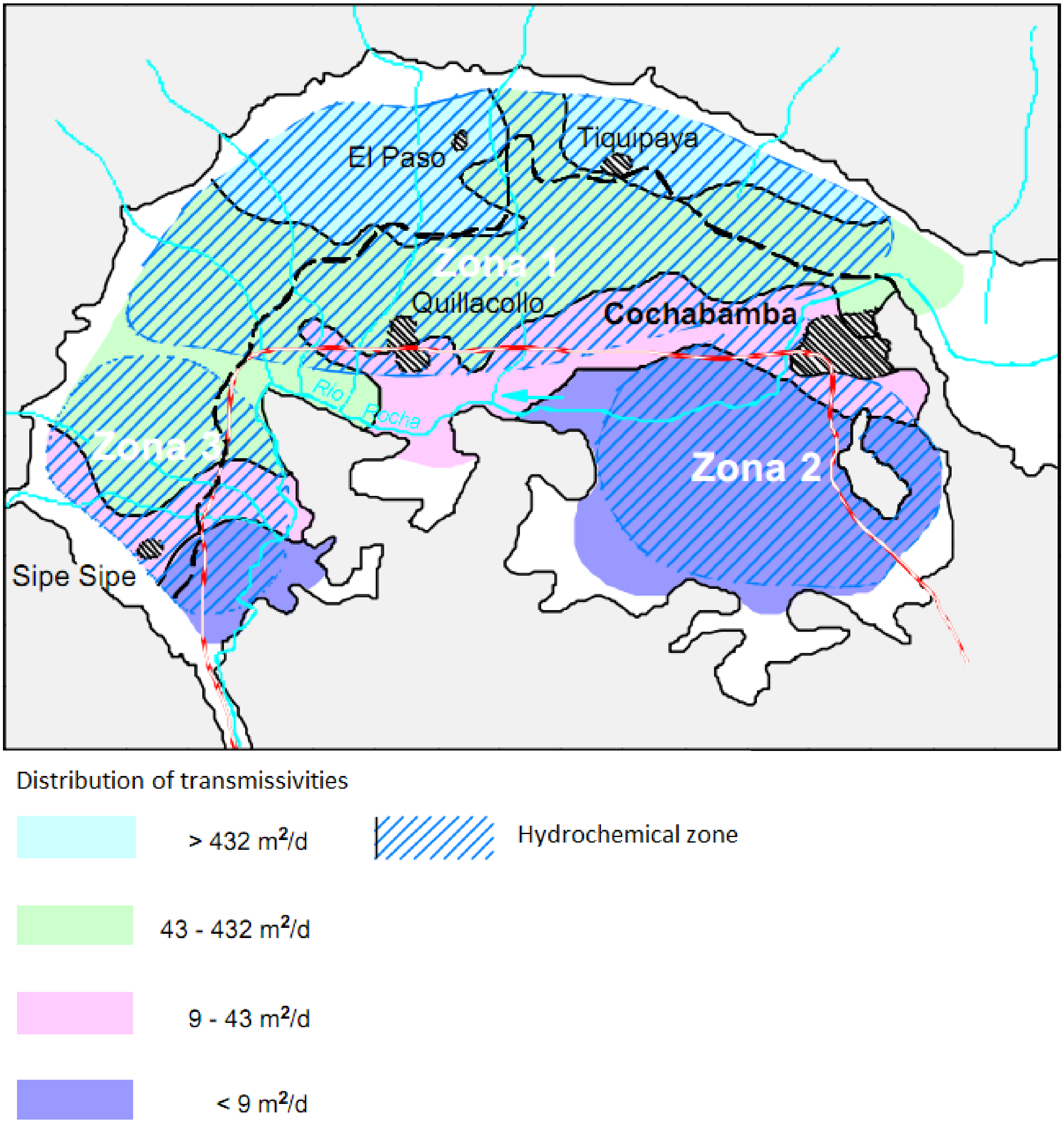


Figure 1. *Transmissivities and hydrochemical zones in the Central Valley of Cochabamba (taken from Neumnann-Redlin, 2000, and modified).*

Fluctuation of the groundwater table over the year varies from about 20 m in the north to less than 1 m in the south. Notwithstanding the large quantities of ground water withdrawn from the valley, the levels of the water table in general did not diminish during the end of the last century; only in locations with an intense exploitation lowered water tables could be observed (Neumann-Redlin, 2000). According to Benjamin Loma, responsible for basic services (servicios básicos) at the municipality of Sipe Sipe, the water tables of the area have not been sinking in recent years, and have a natural variation of about one meter over the year. Loma also states that the groundwater contains much salts and calcium, and that the municipality does not have any information about wells in the area (interview, 2010-04-06).

In 1996, total groundwater recharge was 66 million m^3 $year^{-1}$, of which 41 million m^3 $year^{-1}$ originated from infiltrating surface water, 17 million m^3 $year^{-1}$ from precipitation, and 8 million m^3 $year^{-1}$ from irrigation. This was in balance with the outflow of sub-surface water from wells (49 million m^3 $year^{-1}$), evapotranspiration from wetlands (11 million m^3 $year^{-1}$), and outflow to rivers (6 million m^3 $year^{-1}$) (Neumann-Redlin, 2000).

2.3.2 Hydrochemics

Three chemical zones can be distinguished within the valley (see figure 1). In zone 1, which approximately comprises the northern half of the valley, the ground water is rich in calcium, magnesium and bicarbonates, and the electrical conductivity varies between 113 and 394 µS cm^{-1}. In zone 2, in the south-east, the waters are more characterized by their sodium and bicarbonate content, and their conductivities vary between 477 and 580 µS cm^{-1}. The third zone, where the cooperative COVIVIR's lot is located, hosts ground waters rich in calcium, magnesium and sulfates, with electrical conductivities of 252 to 2100 µS cm^{-1} (Neumann-Redlin, 2000).

2.3.3 Groundwater conditions at the site of COVIVIR

According to Mauricio Solis at the well-drilling company Hidro Drill, groundwater resources are plentiful in and around Sipe Sipe, since it is a recharge area, where substantial amounts of water enters the deeper aquifers from the mountains. The rainwater falling close to COVIVIR's lot usually only reaches the upper aquifers due to impermeable clay-layers in the ground, and the waters of those shallow aquifers are usually not suited for drinking due to high levels of contamination (Solis, interview 2010-05-11).

One well is already present at COVIVIR's lot, and another two are located within a few meters from its north-eastern corner (see appendix I). The water level of the well located at the lot has been measured twice, both times during the rainy season. The first time it was measured, the level was observed by Jorge Heredia to be located 16 meters below the ground level; it is unknown whether water recently had been extracted from the well. The second time the water level was measured (at the 28th of April 2010 by the author of this thesis), it was located 15.2 meters below ground level; water had then been extracted the previous day for construction purposes.

One of the other two wells mentioned above is used to extract potable water and is tapped (see section 3.1.1 for more information about this well), and the other one has presumably been used for extraction of irrigation water, but now sludge of a stale smell reaches the water level of the water table. The water level of the latter was at the 28th of April 2010 observed by the author of this thesis to be located at 14.0 meters below the ground level, and has earlier been observed to be located at 14.6 meters below the ground level by Jorge Heredia.

2.4 Tank trucks

A common solution in the area is tank trucks that bring water. This water is, however, significantly more expensive than that delivered through pipes. The trucks also regularly fail to deliver water as agreed, adding a factor of insecurity. Moreover, delivering water by trucks instead of pipes imply an extra environmental impact.

2.5 Field work

A test of the groundwater quality was performed at the laboratory of the division Centro de Aguas y Saneamiento Ambiental (C.A.S.A.) at the university Universidad Mayor de San Simón in Cochabamba. Water was fetched at the 17th of May 2010 by C.A.S.A. personnel at a tap located some tens of meters from the lot's northern boundary. The water originated from the OTB Convento's well located close to the lot (see section 3.1.1), and had thus undergone storage in an elevated tank, which in case of the tank not being maintained properly could have caused bacteriological contamination. A set of standard parameters were examined, shown in appendix IV.

The water tested has a quality that according to the laboratory staff makes is apt for household use. No pathogens were found. Sulfate contents and hardness show values that surpass the Bolivian norms, but according to Rosario Montaño at the laboratory, these values do not make the water directly hazardous to human health (interview 2010-05-28). Some aesthetic and practical problems could occur, though, like unpleasant odors (caused by sulfates) and clogged pipes in household machinery (caused by hardness).

High sulfate content in drinking-water could have laxative effects and cause diarrhea, especially for infants and people not used to high sulfate concentrations. It is difficult, though, to specify a level at which health risks occur, but many people seem to experience problems if sulfates concentrations are about 750-1000 mg liter^{-1}. The concentration found in the water of the OTB Convento's well was 400 mg SO_4 liter^{-1}.

Groundwater parameters might vary somewhat depending on the season. April is a good month to get results that are representative for the rainy season, since that month is at the end of that season, while October is a good month to test parameters for the dry season. Apart from this variation, parameters vary little over time, and thus normally no more than one test is needed for each season. If some parameters are close to limits stated in norms or such, though, additional tests might be needed (Montaño, interview 2010-04-19). The time frame of this study, though, does not allow for parameters to be tested for different seasons.

2.6 Conclusions and recommendations

It is obvious that surface water cannot be an option due to high levels of contamination, scarcity, unavailability and intermittency. Rainwater could be an option for the future if groundwater becomes scarce. The only option for a safe year-round water supply as things are at the present is to exploit the groundwater, which according to all available sources is rather plentiful in the area. The quality of the groundwater of the aquifers located at a sufficient depth is also satisfying, although the water generally shows rather high levels regarding hardness and sulfate content.

Recommendation: The local groundwater should doubtlessly be used, although NOT from the most shallow aquifers for potable purposes.

3. Water systems

In this chapter, available options for water systems are discussed and evaluated. These include wells for groundwater extraction, water distribution systems, water heating, and potabilisation of water that might contain pathogens. Costs, comfort and environmental impacts are taken into consideration, and at the end of the chapter, recommendations are made.

3.1 Systems for groundwater extraction

Since the local groundwater will be recommended as the source of household water (see section 2.6), the question is whether the cooperative should be affiliated to a nearby well operated by others, or drill its own well. Costs in the short and long term are important issues for Procasha and the cooperativists of COVIVIR, as well as water quality and security, but also environmental issues are given great concern.

3.1.1 Affiliating to an existing well

The most convenient alternative to access the groundwater would be to connect to a well with an elevated tank located only about 10 meters from the lot's boundary. The well and tank are operated by a so called OTB (*Organización Territorial de Base*, or *Base Territorial Organization*), which is a type of organization introduced by the 1994 law *Ley de Participación Popular (Law of Popular Participation)*. Each OTB encompasses a certain amount of land, together with its dwellers, and is operated by local people. The OTBs' main assignment is to negotiate with the authorities, representing the members (Landaeta, 2004), and every Bolivian is a member of an OTB (Lema et al., 2001). The municipality of Sipe Sipe is divided into 72 OTBs (Ala Quiroz, 2010, s. 75). The name of the OTB that operates the above mentioned well is *Convento*.

The cost of affiliating to the elevated tank and well mentioned above is, according to the OTB Convento's president Cresencio Abasto (interview 2010-05-27), a one-time fee of US$ 500 for every household, and the price per m^3 of water used is 1 boliviano. Until recently, the price of affiliation was US$ 1000 per household, which the cooperativists were not willing to pay since they thought it was too high; OTBs normally charge about US$ 500 as a one-time affiliation fee.

According to the lawyer Dionicio Saravia, who is frequently consulted by Procasha, the OTBs are prohibited by law to sell water in such a way. Saravia further states that if any technical problems would occur after affiliation, impeding the deliverance of useful water (for example if the well would dry out, if the water quality would drop significantly, or if the technical system would fail), COVIVIR would have no legal means of getting compensated for their investment. If the OTB would, however, consciously close down the water supply, it would be committing a crime and COVIVIR could take legal action. The cost for COVIVIR of pursuing such a juridical process would be in the range of US$ 500, a cost that they would not be compensated for even if the OTB would be convicted (Saravia, interview 2010-05-18).

No written material about the OTB's well is kept by the persons in charge of it; the documents have, according to Cresencio Abasto, been lost over time. Abasto has, though, handed over a hand-written paper to the writer of this thesis, containing a number of well parameters which he claims to have obtained from the people responsible for the well. These parameters are:

- Depth: 85 meters
- Width of filters: 6 inches
- Location of the motor: 35 meters depth
- Filter types: Johnson
- Static water level: 18 meters
- Dynamic level: 12 meters

At least one of these parameters are obviously incorrect, since the dynamic water level per definition must be lower than the static one (the dynamic water level is the depth at which the water table stabilizes after an extended period of pumping, while the static level is the level before pumping). Therefore, one should perhaps be careful in trusting the other numbers as well.

Abasto claims that the well was constructed in 1999, and that it has a maximum capacity of delivering 14 to 15 liters of water per second, but that at the moment much less water is extracted due to low demand for water. The elevated tank in which the water is stored has an inner volume of 45,000 liters and is cleaned once every month (Abasto, interview 2010-05-17).

3.1.2 The lot's existing well

A well is already located on the lot. According to measurements performed by an engineer hired by Procasha (Julio Rodriguez Humerez, consultant engineer at the company Proyectos de Ingeniería), the well is 18 meters deep. It has concrete walls at its highest section, reaching a couple of decimeters above the ground, and at its deepest few meters. The rest of its walls are uncovered soil. The well has been used for fetching irrigation water, and lately for fetching water used in the construction of the centro comunitario, mainly for mixing concrete. The water is fetched using a bucket connected to a rope.

This well is far too shallow to serve as drinking water supply for COVIVIR, not only because its capacity might be too small, but also because the waters of the shallow aquifers are too contaminated to serve as drinking water. At best, this well could be used as a starting point for the drilling of a new well – which might save the costs and effort of 18 meters of drilling.

3.1.3 Drilling a new well at the lot

According to the hydrological engineer Mauricio Solis at the well-drilling company Hidro Drill located in Cochabamba (interview 2010-05-11), it is likely that it would be more feasible to drill a completely new well than to upgrade the one that is already sited at the lot, since that well is very shallow. Solis claims that a normal depth of a well located in the area of COVIVIR, with a sufficient capacity for the cooperative, would be about 120 meters. Hidro Drill normally drills wells with three different filter sizes; 4, 6 and 8 inches. A 4-inch filter well would, according to Solis, be too small to fit a sufficiently big pump, while a 6- or 8-inch filter well would be feasible, a 6-inch well being the least expensive option. Normally, the company charges US$ 180 to 250 per meter of drilling for wells with a width adapted for 6-inch filters, the price depending mostly on how rocky the soil is (the more rocks, the higher the price). Alfredo Duran at the division Centro Agua (Water Center) at the university Universidad Mayor de San Simón in Cochabamba confirms that this is a rather normal price for drilling wells in the region, given that equipment such as filters and tubes (but not necessarily a pump and electrical installations) are included in the price (interview 2010-05-13). The maintenance cost for such a well would be about US$ 1200 per year if regularly maintained – but would probably end up higher if maintenance is neglected, which is often the case (Solis, interview 2010-05-11).

Hidro Drill recommends that sounding is performed before drilling a well. The sounding is a so called *vertical electrical sounding*, which by measuring the resistivity of the ground can give information about some soil characteristics at the depths of interest (Jahani, 2005). This method gives information about at which depths the soil is likely to host aquifers of suitable characteristics, i.e. where to place the filters. Hidro Drill charges US$ 250 for each sounding, and two or three soundings are needed for each spot that is examined; if three soundings are performed, the resolution will be higher. If, after performing soundings, Hidro Drill is consulted for drilling a well, the soundings will be free of charge (Solis, interview 2010-05-11). Since the soundings give information about the soil characteristics, information about the soil's rockiness is obtained, which gives a hint about the final drilling cost (Solis, interview 2010-05-13).

Using the above numbers, the cost of drilling a 120 m deep well can be roughly estimated to be somewhere in between US$ 21600 and 30000, equipment included. To this comes the cost of about US$ 12000 for an elevated tank (see section 3.2), which makes the initial investment cost for the system as a whole US$ 33600 to 42000.

3.2 Water distribution systems

If a new well is drilled on the lot, a system for maintaining a sufficiently high pressure in the water pipes has to be installed. Two varieties are commonly used:

1: an elevated tank is constructed, through which the water's energy of position provides pressure at lower levels, or

2: one or more pneumatic tanks are installed, in which compacted air guarantees that a sufficient pressure is maintained, while the submergible pump of the well (which in this case has to be of significantly higher capacity than for the other option) regularly pumps water into the tank when the air pressure drops to a certain level.

If option 1 is to be used, the tank and its structure would, in a case like COVIVIR's, normally be constructed in concrete and have a height of 9 meters, the tank having a capacity of holding 15 to 30 m^3 of water. The tank would be equipped with an electrical switch that signals to the submergible pump to start as the water level drops to a certain level, and another device that signals to the pump when to stop. An advantage of option 1 compared to option 2 is that sand and other solids accumulate at the tank's bottom, which prevents them from entering the pipes where they would sediment and eventually cause problems. The cost of hiring a construction company to construct such a tower with an elevated tank would be about US$ 12000 (Solis, interview 2010-05-12).

If option 2 is to be implemented, a submergible pump with an about 5 to 10 times larger effect will have to be used compared to if option 1 is chosen. This system would consume a significantly larger amount of energy, and the larger pump is more expensive to buy. Altogether, option 2 would be significantly more expensive to implement than option 1, and the benefits that option 2 might have under certain conditions do not motivate this extra cost in the case of COVIVIR (benefits include reduction in pressure difference for high buildings, and an aesthetic benefit as a tank-tower is not needed). The pneumatic tank or tanks would have to have a very large accumulative volume to prevent the pump from starting to often, which could cause it to get over-heated and damaged. Each startup also accounts for a significant part to the pump's total energy consumption (Solis, interview 2010-05-13). Altogether, according to Solis, option 1 is in COVIVIR's case clearly recommendable over option 2.

It should be considered that in the rural electricity grids of Bolivia, voltage is often volatile, especially at the evening peak hours (i.e. 18:30 to 21:00; the peak of the morning hours, at 06:00 to 07:00, is usually not as big of a problem, partly because street lights are not lit at these hours). These fluctuations could damage the pump's engine, and therefore a timer should be installed that keeps the pump turned off during those hours (Solis, interview 2010-05-12).

If COVIVIR, on the other hand, chooses to affiliate to the well and elevated tank operated by the OTB Convento, no system for water pressure maintenance will need to be needed, which saves cost and environmental impact from construction and/or electricity consumption.

3.3 Potabilisation of water

Although the groundwater in and around Sipe Sipe is often suitable for drinking without prior treatment, boiling the water before drinking it, in order to avoid the risk of being infected by pathogens, is widely practiced, a habit which due to the high specific heat capacity of water is quite energy consuming. Besides the fact that the groundwater itself might be contaminated, water often gets polluted during storage and transportation; a tank that has not been cleaned in a while, or long retention times in warm pipes, might allow for pathogen contents to grow to unhealthy levels. Below, two easy, cost efficient and environmentally friendly methods for water potabilisation that contains pathogens are presented.

3.3.1 UV desinfection

The UV radiation of the sun has the capability of killing pathogens. A simple method of taking advantage of this fact is to fill PET or glass bottles with water and leave them in the sun for a minimum of five hours during day-time. The effect will be better if the bottles are placed at a reflecting surface, e.g. a metal roof (Franken, 2007). There are also special appliances designed for the purpose, for example the Swedish invention Solvatten, that also has a filtering device for removing larger pathogens that are not killed by the UV radiation (see www.solvatten.se for more information).

3.3.2 Solar water pasteurization

Solar cookers use reflecting surfaces to concentrate the solar radiation to a vessel. Pathogens are killed at about 65^{o}C. Simple solar cookers can pasteurize about one liter of water per hour. The Cochabamba climate offers lots of sunny days, and the altitude makes the sun radiation stronger than at sea level, facts which further increase the benefits of using solar cookers in the region.

Figure 2. *A solar cooker, shown at an exposition in Cochabamba.*

3.4 Water heating systems

Water has a particularly high heat capacity, which means that a proportionately large amount of energy is needed to change the temperature of any specific amount of water, compared to the same amount of most other substances. Thus, the water heating system is one of the critical spots of the typical dwelling house when it comes to environmental impact – and one should also keep in mind the present and future costs of energy; as global fossil fuel resources become scarcer, energy prices are not unlikely to sky-rocket.

3.4.1 Electrical water heating

An electrical water heater installed in the shower-head is probably the most common solution in the region. It has the benefit of imposing a low initial cost as the equipment is quite cheap. However, from a sustainability perspective it is favorable to keep the electricity consumption as low as possible; even though most of the electricity in South America is produced by hydro power, wasteful use of electricity implies that the possibilities of exporting surplus electricity (perhaps to regions where coal is used for electricity production), or to use it for other purposes (e.g. for electric cars), is forfeited. One must also keep in mind that hydro power production, although not directly emitting CO_2, always implies a certain degree of environmental (and in many cases adverse social) impact, which might be of substantially different magnitude and character.

3.4.1.1 Cost efficiency

A back-of-the-envelope calculation of the costs of electric water heating was made, using the following assumptions:

- each person showers five minutes per day, and each household consists of six persons,
- a shower head uses about 10-25 liters of water per minute, depending on the model (Solana and McMordie Stoughton, 2007),
- the incoming water has a temperature of 20^{o}C, and is heated to 40^{o}C,
- the electric water heater has an efficiency of 100%,
- the specific heat capacity of water, C_p, is 4.18 kJ kg^{-1} K^{-1} (one kWh equals 3.6 MJ), and
- the price of electricity in Bolivia is about US$ 0.06 per kWh (The World Bank, 2010-09-05).

The yearly energy use for electrical shower water heating for a family of six then would be, with a water efficient shower head which uses 10 liters of water per minute:

- $6\ [p] \cdot 5\ [min] \cdot 10\ [l\ min^{-1}] \cdot 365\ [d] \cdot 20\ [\Delta T] \cdot C_p = 9$ GJ

If a normal shower head is used, about the double amount of energy (and water) would be consumed, given that the water pressure is high enough.

This gives a cost of about US$ 150 to 300 per year for each household, depending on which shower head is used. Please keep in mind that the Bolivian electricity prices are low in comparison to the typical South American prices, and that prices (or availability) quickly and dramatically can change depending on political decisions, increased energy use by the whole of society, or other factors.

3.4.2 Gas water heating

Apart from the large initial investment cost, gas heating implies an extra risk, to a large extent depending on the quality and maintenance of the equipment installed – carbon monoxide poisoning caused by domestic gas systems causes not only a number of deaths every year, but also other adverse health impacts.

3.4.3 Solar water heaters

In a solar water heating system, sunlight is used to heat water, which is usually stored in a thermally insulated tank to be available at a desirable temperature at all hours of the day. Since water heating is very energy consuming due to the high specific heat capacity of water, the potential for energy savings is large; solar water heaters have shown an energy payback time of about 0.5 years (Muneer, 2006). Under the right conditions, solar water heating is a cost-efficient solution.

Three main types of solar water heaters may be distinguished: *thermosyphon*, *built-in-storage* and *forced-circulation*. The thermosyphon and built-in-storage types may also both be referred to as *passive systems*, as no pumps are needed to make the water circulate; the forced circulation type, on the other hand, is often called an active system, since an external element (such as a pump) is needed to drive water circulation. There are two ways to heat the water; either, the water is heated directly by the sunlight in the collector in a so called *direct system*, or the water is heated by heat-transferring fluid run through the collector and a heat exchanger in the tank in a closed loop – a so called *indirect system* (Asif and Muneer, 2007).

In a thermosyphon system, the fact that the density of warm water is lower than that of cold water is taken advantage of to make the water circulate through the system. The collector is placed lower than the storage tank, which makes cold water sink to the collector. At the collector's outlet, hot water rises to the tank. In a built-in-storage system, the tank is built into the collector (Asif and Muneer, 2007).

In cold climates, the water could freeze during winter time, damaging the system. Systems for anti-freezing are available, but they imply raised costs and decreased efficiency.

3.4.3.1 Cost efficiency

A system with a 200 liter tank (dimensioned for a household of six persons) manufactured in Cochabamba by the company *Sico sol*, costs slightly more than US$ 1000, depending on the quality – with copper pipes, the system will have a longer lifetime than if the pipes are made out of some cheaper material. Different qualities give different life spans, varying from 10-15 years to 20-25 years.

According to a company brochure handed out at an exposition in April 2010, the system has an economic payback time of 3.5 years compared to an electrical water heating system. As found in section 3.4.1.1, the yearly cost of an electrical water heater for a shower can be roughly estimated to about US$ 150 to 300, which would give a payback time of about 3 to 7 years if only the hot water used for showers is considered (and shorter payback times if also hot water for other purposes is included). These numbers should be read cautiously, though, since the assumptions for the back-of-the-envelope calculation are associated with great uncertainties.

3.5 Bathroom equipment

The right bathroom equipment could save water, e.g. high-efficiency toilets, water taps and shower heads. High efficiency water taps and shower heads have the characteristic that the water consumption per unit of time increases very little with an increase in the pressure, due to more air being mixed with the water. Thus, water is substituted by air, and the water savings are 40 to 50% (Franken, 2007). These appliances can also come with a thermostat, which keeps the temperature constant, avoiding losses of hot water while manually setting the desired temperature (Franken, 2007).

3.6 Conclusions and recommendations

3.6.1 Recommended system for groundwater extraction

Uncertainties make it impossible to determine in advance the costs of each of the two options, i.e. affiliating to the OTB's well or drilling a new one. Uncertainties include the arbitrariness of the OTB regarding the price they might charge for affiliation, unknown properties of the existing well, and unknown geological and hydrogeological conditions. The depth of the wells should also be considered here; a deeper well means that it will be more protected from contamination, but more expensive to drill. Also the lifetimes of the wells should be considered, but cannot easily be estimated for the OTB's well due to lack of information. If constructed properly, however, the lifetime of a well should be about 50 to 100 years.

From an ecological point of view, the best option would most certainly be to affiliate to the OTB's well, since the construction of a new well implies consumption of energy and materials, while the affiliation would mean that existing infrastructure is shared. The drilling of a new well would also imply increased risk of future groundwater pollution if the well, when abandoned, is not sealed properly (see section 5.2).

Recommendation: Given the information that is currently available, it is recommended that COVIVIR should affiliate to the nearby well operated and owned by the OTB Convento.

3.6.2 Recommended system for water heating

The most sustainable option from an environmental as well as from an economic perspective is to use solar water heaters. Solar water heaters also provide the comfort demanded by modern households, given that sufficiently large tanks are installed to provide sufficient amounts of hot water at all times of the day.

Recommendation: Solar water heaters are strongly recommended.

3.6.3 Other recommendations

It is recommended that water-efficient equipment for kitchens and bathrooms is actively searched for, e.g. high-efficiency shower heads and water taps, which for a small investment cost could provide large savings in water and energy. It is also recommended that, if water disinfection is to be practiced, another method is chosen than boiling the water at the stove – in order to save energy, UV disinfection or solar pasteurization could be practiced.

4. Wastewater systems

In this chapter, different methods for small-scale wastewater treatment are discussed regarding their feasibility for COVIVIR. Dry toilets, which offer a possibility to avoid black wastewater and provide potent fertilizers, are also discussed, and the possibilities for wastewater reuse are examined. Costs and environmental impacts are at focus, as well as social aspects. Finally, proposals for solutions are made.

It has already been decided that the centro comunitario will have its own system for wastewater treatment, since the cooperativists need toilets, showers and a kitchen while constructing the dwelling-houses (which will start to undergo construction after the centro comunitario has been completed). A septic system has been designed for the blackwater from the toilets at the centro comunitario, and the pits and canals for the equipment have been dug. A separate system for ground infiltration of graywater from the kitchen, showers and hand basins has also been designed and partly constructed. A wastewater treatment system for the dwelling houses has, however, not yet been designed.

4.1 Septic tank with infiltration

A septic tank with subsequent infiltration is a very common solution for domestic wastewater treatment throughout the world. Generally, it is recommended that the water be infiltrated in a so called *drain field*, where the water enters the soil through perforated pipes dug into the ground. In Bolivia, however, a very common solution is to simply let the water infiltrate through a hole in the ground, a so called *seepage pit*.

The method of letting domestic wastewater infiltrate the ground could offer a cheap and simple way of cleaning the water sufficiently under the right conditions. Under unfavorable conditions and if care is not taken, however, a septic system could cause groundwater pollution, surface water eutrophication, or other problems. Soil characteristics, local hydrogeological conditions, as well as distances to objects sensitive to pollution such as nearby wells and watercourses, are all critical factors that have to be considered when the feasibility for such a system is determined. Also proper maintenance of the system is critical.

How well suited a soil is to treat wastewater depends on four factors:

- the amount of accessible soil particle surface area,
- the chemical properties of the surfaces,
- soil environmental conditions, such as temperature, moisture and oxygen (O_2) levels, and
- the nature of the particular substances in the wastewater.

(Washington State University, 2010-07-03)

The total surface area of a soil depends heavily on the particle-size distribution; the smaller the grains, the larger the accumulative surface of any given volume of the soil. On the other hand, if the grains are too small (as in clay) the hydraulic conductivity of the soil might be too small for infiltration to take place at a sufficient rate. It is also preferable that the soil not be saturated, since saturation allows for less surface contact – in a soil that is not saturated, the water travels along the particle surfaces through capillary flow while much of the pore space is filled by air, allowing for more contact than if the pores are completely filled by water (Washington State University, 2010-07-03).

Current Bolivian national regulation stipulates the following minimum distances between any septic tank and:

- sources of water (use is not specified): 20.00 meters,
- boundaries to other properties: 2.00 meters,
- the system of final disposition of the water: 2.00 meters,
- present or future constructions within the property limits: 2.00 meters,
- constructions on bordering properties: 5.00 meters,
- subterranean storages of drinking water: 10.00 meters.

(República de Bolivia, 1994, s. 111)

However, many national regulations are under revision, which might lead to some of them being tightened up (Saravía, interview 2010-04). Distances of a similar magnitude are used in for example U.S. norms, even though they might vary from state to state.

4.1.1 Leach fields

A leach field is an area in which perforated pipes have been dug into the ground to allow septic tank effluents to infiltrate. The perforated pipes are put in trenches that are 45 to 60 cm wide and preferably no more than 60 cm deep. The trenches should be filled with gravel. The total area needed depends on the soil's characteristics, the amount of wastewater, and how polluted the wastewater is. Leach fields are generally recommended as a good method for treating septic tank effluents, if suitable soils can be found in the area (i.e. soils that are neither too permeable nor too impermeable). The distance from the bottom of the trenches to the highest groundwater level, to bedrock, or to watertight layers of clay, should preferably be at least 1.2 meters. Leach fields should not be constructed where the soils have slower percolation rates than about 25 minutes cm^{-1} (Salvato et al., 2003), a criteria that is fulfilled at the spots where percolation tests have been performed at the lot of COVIVIR (see section 4.5).

4.1.2 Seepage pits

In the region, the common solution for septic effluent infiltration is a seepage pit, which is basically a hole in the ground from which the water percolates into the surrounding ground. However, such a system under many circumstances does not provide sufficient water treatment. The obvious benefit is that it is simpler and cheaper to construct than a leach field, but since the effluents are spread over a much smaller area, higher demands are put on the surrounding soils and the hydrogeological conditions.

A seepage pit should not be located closer than about 50 meters from any drinking-water well. Nearby wells should also preferably be located higher than the seepage pit, and it is preferable that the bottom of the pit be at least 1.2 meters above the highest groundwater level (Salvato et al., 2003). However, in areas where the groundwater is used as a source for drinking-water, seepage pits should generally be avoided in favor of a more diffuse system, such as a leach field (Salvato et al., 2003).

The walls should be reinforced to prevent them from collapsing. The hole could also be filled with rocks, supporting the walls. The hydraulic load should generally be kept between 16 to 32 liters day^{-1} m^{-2}, accounting only for the wall area (i.e. not including the bottom area) (Salvato et al., 2003).

4.1.3 Conditions for the centro comunitario

For the centro comunitario, the Procasha technical staff has designed a septic system consisting of a septic tank followed by a seepage pit with a depth of about 2 m and a diameter of about 1.5 m. It will be filled with filtrating material (rock material of different coarseness). An excavation has been dug, in which the soil profile shown in figure 3 can be observed. Diamicton is a poorly sorted sediment, which means that it contains a wide range of granular sizes. In this case, the diamicton contains rocks, gravels, sands, silt and perhaps a little clay. It is considerably more permeable than the clayey silt present at the sight.

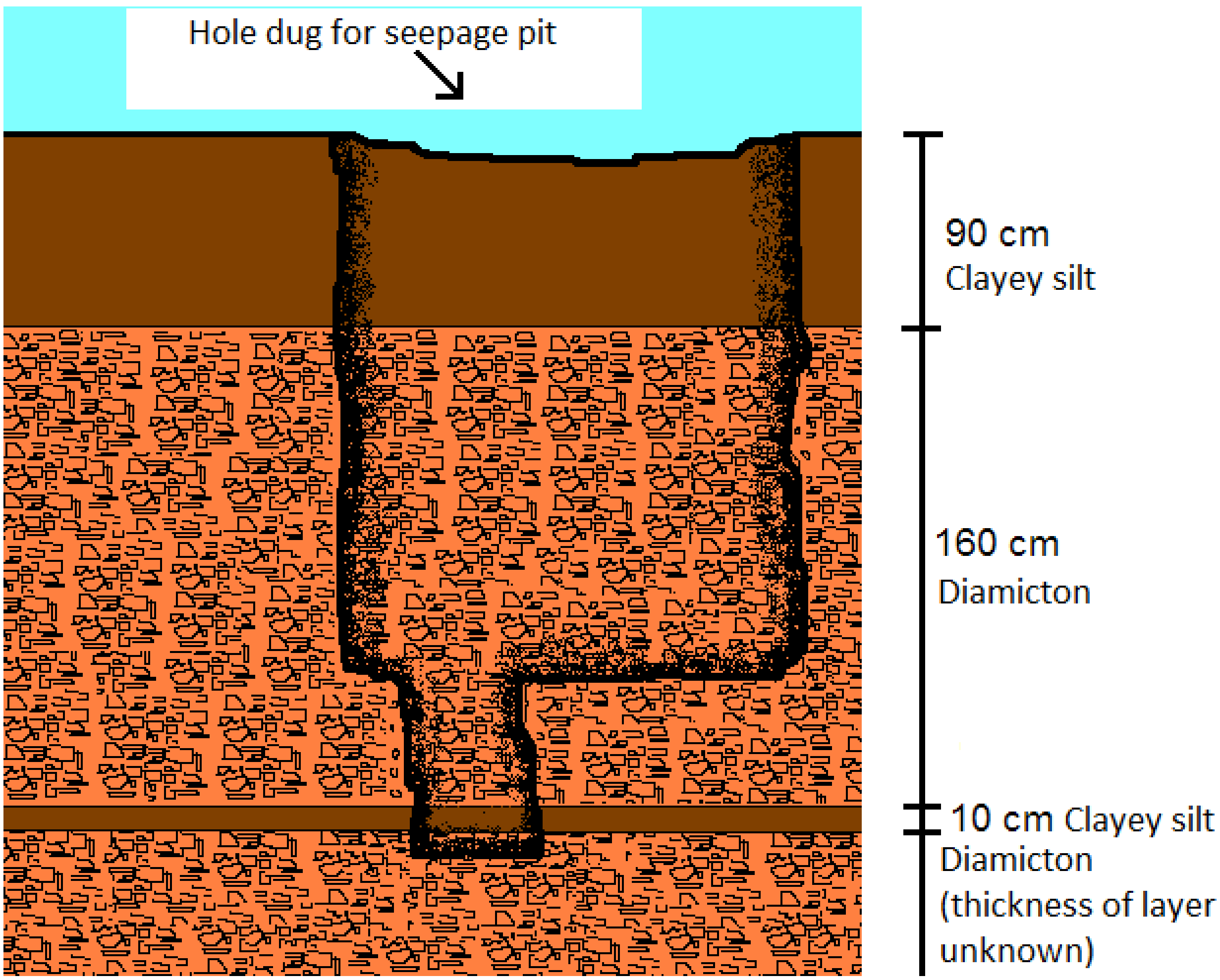


Figure 3. *Thickness of the soil layers observed in the hole dug for the infiltration well for the centro comunitario,* and in a smaller hole at its bottom excavated for a percolation test.

No diamicton layer was observed during the geological investigation carried out by consultant engineers, during which three perforations to a depth of four meters were performed in different parts of the lot (see appendix V), nor in the excavation for the water tank at the other side of the building. The writer of this thesis has been able, though, to spot two soil layers that seem to contain significant amounts of coarse gravel or rocks using a flashlight, looking down the walls of the well located at the lot. The layers seem to be well defined, and they extend from a depth of 1.5 meters to a depth of 2.1 meters, and from a depth of 5.4 meters to a depth of 8.4 meters (the depths were measured by sinking a measuring-tape down the well). To be sure that these layers are permeable and extensive enough, however, additional tests would be needed – tests beyond the range of this thesis.

Even though the diamicton certainly offers sufficient permeability without being too permeable (which can be the case for coarser materials), the vertical and horizontal extension of the diamicton layer is unknown. If it is not extensive enough, the water could get "trapped" between walls of impermeable soils, causing system failure.

4.1.4 Conditions for the dwelling houses

Since the geology varies considerably over the lot, and permeable soil layers have only been observed at a few spots (see section 4.1.3), it cannot be assumed that good conditions for infiltration can be found without problems. Special care needs to be taken if an infiltration system is to be constructed in the more impermeable soils that seem to dominate the lot – a quite large infiltration area would probably be needed.

4.2 Constructed wetlands

Constructed wetlands offer a relatively new method for wastewater treatment, which imitates natural processes occurring in natural wetlands. They can be used to clean wastewater from households, agriculture and industries, as well as storm water, coal mine drainage, and other contaminated waters (Davis, 1994).

Constructed wetlands can be divided into two types: subsurface flow (SSF) wetlands (also known as vegetated submerged bed (VSB) systems) and surface flow (SF) wetlands. In turn, SSF constructed wetlands can be divided into the two subgroups of horizontal flow (HF) and vertical flow (VF) systems (Langergraber, 2005). A SF wetland will not be suitable in this case since the water table is free, which might cause odor, problems with mosquitoes, and health hazard to children playing in the area. Therefore, this thesis will further on only discuss SSF constructed wetlands.

The SSF constructed wetland consists of a watertight depression in the ground filled with a media (normally gravel) through which the contaminated water flows. A bed of aquatic plants is growing in the media, their roots participating in the cleaning process. This environment of organic and inorganic materials fosters a diverse population of microorganisms that break down a variety of undesirable substances (Davis, 1994). The plants may also add aesthetic value and biodiversity to the area, and the treated water can be used for irrigation.

SSF constructed wetlands should normally not be used to clean black water, why in the case of household wastewater cleaning, a septic tank for sedimentation of solid material needs to be installed "upstream" from the wetland. After passing through the septic tank, the graywater slowly pours through the wetland while nutrients, pathogens and other pollutants are reduced in different processes. Several mechanisms work together to clean the water. Firstly, filtration is important to remove dissolved solids. Pollutants are taken up by the plants, and transformed or removed by microorganisms. Microbes are able to transform organic nitrogen into inorganic forms (NO_3 and NH_4) that can be taken up by the plants (EPA, 2004a).

Constructed wetlands is a solution that is often less costly to install than conventional treatment systems. They are also cost-effective regarding operation and maintenance, and can handle fluctuations in the water levels (EPA 2004). The space required could be as low as 1 m^2 $person^{-1}$, and the plants that grow in the wetland can be used as animal feed or for other purposes that may improve the economy of people in sub-developed regions (Franken, 2007).

There are a number of SSF wetlands in operation in the valley, whose performances and feasibilities have been studied by prior MFS students. The results are positive; the climate in Cochabamba is suitable for constructed wetlands, and the wetlands offer a cost and energy effective solution that requires little maintenance and (Cordesius and Hedström, 2009; Spångberg and Söderblom, 2008).

4.2.1 Pollutant removal

-Metals

Metals are primarily removed in SSF wetlands by two mechanisms; firstly, metals like Zn, Cr, Pb, Cd, Fe and Al are associated with particles, which are efficiently removed through filtration. Secondly, sulfide precipitation occurs as sulfates are reducted to sulfides in the absence of nitrate, which makes some metals insoluble; this process leads to significant removal of Cu, Cd and Zn (EPA, 1999).

-Nutrients

Nutrients in insufficiently treated wastewaters, mainly nitrogen (N) and phosphorous (P), is a major cause of eutrophication in rivers, lakes and coastal areas. Constructed wetlands have shown good results as nutrients removers. Since nutrients are taken up by the plants that grow in the wetland, they can be reused; the plants are simply composted and the resulting soil is brought back to agriculture.

-Pathogens

Pathogens, i.e. microorganisms that cause disease to its host, constitute a major health concern regarding domestic wastewater. Constructed wetlands will, if properly constructed and maintained, neutralize a good portion of them.

-Organic matter

Organic matter implies a high biological oxygen demand (BOD). If water with a high BOD level is released into rivers and lakes, ecosystems might be damaged as oxygen levels sink. BOD is significantly reduced in a constructed wetland.

4.2.2 Vegetation

A bed of aquatic plants adapted to the climate should be planted on the wetland, with density 0.3 to 1 meters centers (EPA, 1999). A well tried option is common reed (*phragmites australis*). Plant roots will typically reach a depth of 15 to 25 cm (EPA, 1999). Right after planting, the water table should be at the same level as the surface of the media to let the plants root, and as the plants grow, the water level should be lowered (EPA, 2009).

4.2.3 Problems

The risks of problems with mosquitoes or odor are greatly reduced with SSF wetlands compared to SF wetlands; if the SSF wetland is properly constructed and maintained, neither of these problems should occur (Franken, 2007; EPA, 1999).

In some cases, problems of grease clogging in the wetland have occurred, for example in a wetland at a school in Cochabamba, where much grease is emitted from the kitchen. Among the cooperativists of COVIVIR, a common source of income is selling food that has been prepared at home, which could imply a large grease load. A larger septic tank, or other grease-separating devises, could prevent grease-clogging from occurring (Müsch, interview 2010-04-12).

4.2.4 Costs

A SSF wetland for a kindergarten hosting about 100 children each weekday has been constructed in Cochabamba at a cost of US$ 3130, including a grease trap tank, a septic tank, an effluent tank with pump and flotation device, and pipes. The single most expensive part of the whole system was the plastic lining, made out of high density polyethylene, which hinders the water from escaping into the ground (Cordesius and Hedström, 2009). Proper plastic lining can be bought from the Cochabamba company Gerimex at a cost of 50 to 60 bolivianos m^{-2} (Müsch, interview 2010-04-12). In the case of COVIVIR, though, a lining is not necessary due to the low hydraulic conductivity of the upper soil layer (see sections 4.2.5 and 4.2.6). This fact permits the avoidance of an unnecessary cost as well as the avoidance of unnecessary material consumption, the latter being preferable from an environmental point of view.

A wastewater pump with a capacity of about 0,8 hp, or about 100 liters $minute^{-1}$, including a flotation device, that tells the pump engine when to start and stop, costs about US$ 330 in Cochabamba. According to Martha Müsch, a normal pump could be used if a filter is added, but the cost would still be about 100-200 US$ (interview 2010-05-21).

The price of the kind of gravel needed is about 80 bolivianos m^{-3}, according to the Procasha architect María Esther Soto.

4.2.5 Design

All constructed wetlands need impermeable walls and bottom, which may be constituted by a plastic lining, a bentonite carpet, or the natural ground if watertight enough. Soils with a hydraulic conductivity of no more than 10^{-8} to 10^{-9} m s^{-1} may successfully serve as watertight material. If not present naturally, clay added as a thick and compacted layer can be a solution (Franken, 2007). The impermeable soil layer should typically be at least 30 cm thick (EPA, 1999).

It is important that the water-table never reaches the surface of the media, so called *surfacing*. Surfacing should be avoided mainly for three reasons:

1. it might cause odor and mosquito problems,
2. it creates a potential health hazard for children and animals, and
3. it reduces the hydraulic detention time, thus worsening the performance of the system.

(EPA, 1999 s99)

Factors causing surfacing include:

1. poor design of the inlet and outlet piping,
2. an inaccurate estimation of the hydraulic conductivity of the media,
3. bad construction, and
4. an inaccurate estimation of clogging due to accumulation of solids and plant root growth.

(EPA, 2009 s99)

In areas with a very wet climate, runoff from the catchment area must be considered when the flow of the wetland is estimated (EPA, 1999). A wetland located in Cochabamba, however, where yearly rainfall is about 500 mm, should not suffer such a hazard if the wetland is not located so that it receives significant amounts of stormwater. At the rather flat lot of COVIVIR, small protecting walls at the limits of the wetland should be enough to eliminate the risk of encountering such problems.

For a SSF constructed wetland, gravel is normally used as media, even though other materials, e.g. plastics, have been used at some locations. Limestone should be avoided since it could be broken up into smaller pieces (EPA, 1999). While a too fine media is likely to cause clogging, a coarser media makes construction and maintenance more difficult, and a too coarse media might worsen the wetlands performance. In the grain size interval of 10 to 60 mm there does not appear to be any significant difference in pollutant removal, and the U.S. Environmental Protection Agency (EPA, 1999) therefore recommends, in compromise between clogging-risk and ease of handling, that average media grain diameter in the treatment zone of the wetland be 20 to 30 mm. The clean hydraulic conductivity of such a media would be about 100,000 m d^{-1}, even though the value after a period of use must be expected to be much lower. EPA (1999) recommends that the following conservative long term hydraulic conductivity values be considered:

at the initial 30% of the bed: 1% of the clean hydraulic conductivity, and

at the remaining 70%: 10% of the clean hydraulic conductivity.

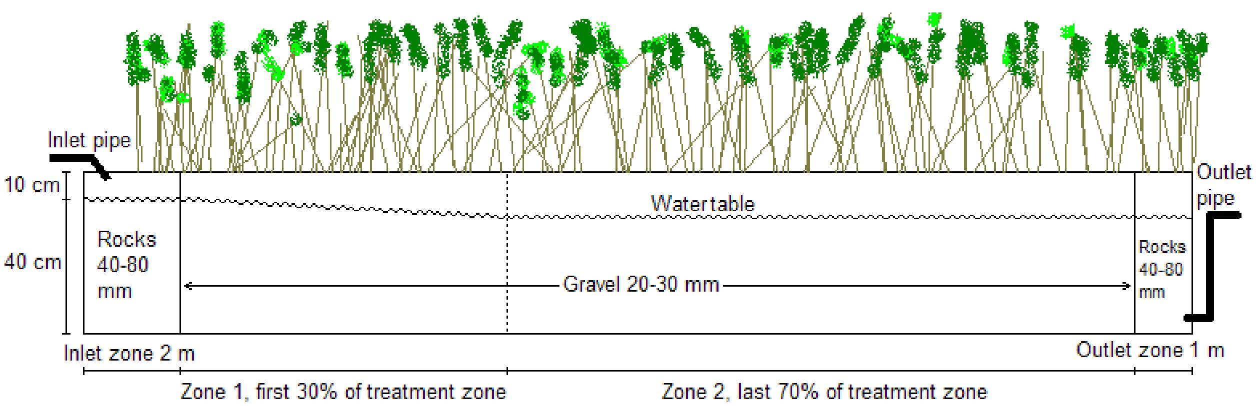


Figure 4. *Schematic drawing of a constructed wetland as seen from the side.*

The media at the first two meters, as well as at the last one meter, of the wetland should be constituted by rocks with a size of 40 to 80 mm, to facilitate distribution and collect the flow, as well as to prevent clogging (EPA, 1999).

The U.S. Environmental Protection Agency (EPA, 1999) recommends that a SSF wetland have a maximum depth (at the inlet, measured from water-surface to bottom) of 40 cm; in a deeper wetland, much of the water would run below the plant-roots, which would affect the performance negatively. The depth of the media at the inlet should be about 10 cm greater than that of the water. The U.S. Environmental Protection Agency also recommends a minimum length of the wetland of 15 m. A slope of the bottom of the excavation of 0.5 to 1% is recommended, mainly to facilitate draining when maintenance is needed (EPA, 1999).

In order to make it possible to control the water level and to drain the wetland, a mechanism at the outlet is usually installed. Figure 5 shows two simple but well-functioning solutions.

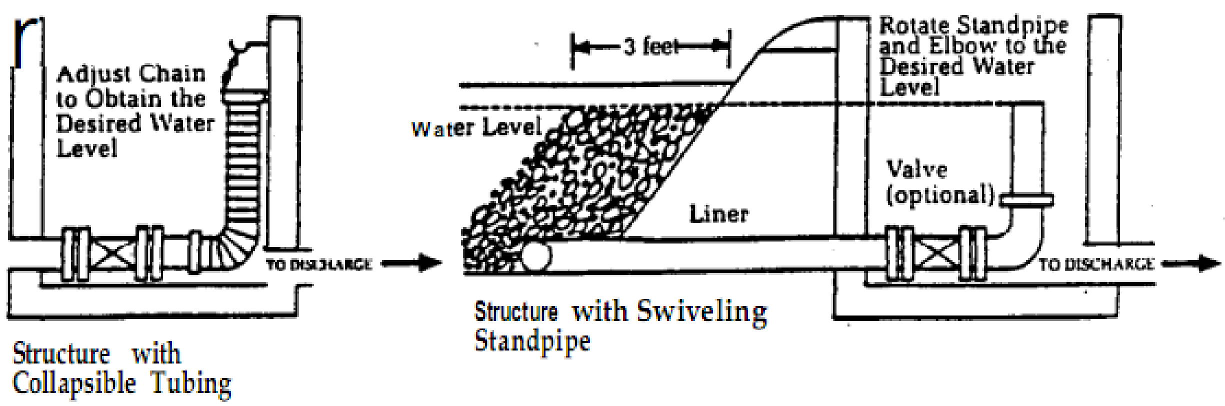


Figure 5. *Examples of mechanisms for water level control at the outlet. Drawing taken from Davis (1994)*.

In order to evenly distribute the water over the width of the wetland, it is recommended to use a perforated pipe that lets the water out across the width of the wetland, see figure 6.

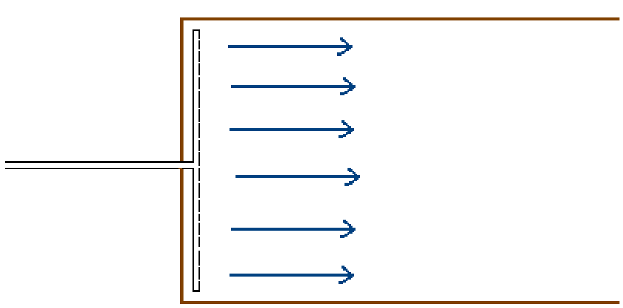


Figure 6. *A perforated pipe distributes the incoming water evenly over the width of the wetland, as seen from above*.

4.2.6 Designing a SSF constructed wetland for the centro comunitario

The Procasha team has given positive signals to the idea of using a SSF constructed wetland for additional treatment of the septic tank effluent of the centro comunitario. Therefore, a design of such a system is provided below.

The septic tank of the centro comunitario has been designed for receiving the blackwater produced by 20 persons (i.e., as if it was to receive the blackwater of the dwellings of 20 persons). A SSF constructed wetland normally has a surface of 1 to 3 m^2 $person^{-1}$, but even though this figure is based on the assumption that all domestic wastewaters, including that from showers, kitchen and such, will be treated, the water from the toilets is contaminated to such an extent that the wetland size still should not be smaller than the above recommendation (Müsch, interview 2010-05-27).

Even though vertical flow wetland have benefits regarding performance and space requirements, they are more costly to construct than horizontal flow wetlands, and since the amount of water that is to be treated in this case is small, the amount of space needed for the wetland will not be a problem even with a solution that requires relatively large amounts of space per person. A vertical flow wetland would also need to be deeper, which in this case means that its excavation would probably reach down to more permeable soil layers, which would mean that some kind of lining would have to be used – which would not be the case if the excavation would not penetrate the highly impermeable layer of clayey silt (see **Fieldwork** below). Avoiding a lining is preferable since a lining would cost money and imply an environmental impact. Moreover, several horizontal SSF wetlands are in use in the valley, which means that competence and experience to maintain this kind of system could be available, while the author of this thesis is not aware of any vertical flow wetland in the region. Altogether, a horizontal flow SSF wetland is therefore recommended and designed.

After length and depth have been decided upon, the head loss, i.e. the difference in water level between the in- and outflow of the wetland, may be calculated using the general form of Darcy's law, assuming laminar flow in all of the wetland (EPA, 1999):

$$\Delta h = QL/(KWD_w)$$

where Δh = head loss due to flow resistance, m
Q = flow rate, m^3d^{-1}
L = length of the wetland, m
K = hydraulic conductivity, $m^3m^{-2}d^{-1}$, or md^{-1}
W = width of the wetland, m
D_w = water depth, m

Cautiously assuming a hydraulic conductivity K of 1000 m d^{-1} (which corresponds to 1% of the clean hydraulic conductivity of the media) throughout the whole wetland, and a water consumption of 100 liters per person (which corresponds to 12 to 17 toilet flushes day^{-1} $person^{-1}$ with the type of toilet that will be used – a cautious estimation since the average American person flushes 5.05 times day^{-1} at their home (Mayer and DeOreo, 1998)), width can be calculated from the above equation in order to prevent surfacing, after deciding a maximum value for Δh (in this case 0.1 m):

$W = QL/(\Delta hKD_w) = 20 \cdot 0.1 \cdot 15/(0.1 \cdot 1000 \cdot 0.5) = 0.6$ m

which multiplied by the chosen length of 15 m would give a surface area of 9 m^2. This area is not sufficient for treating the wastewater of 20 persons, since an area of 1 to 3 m^2 $person^{-1}$ is recommended; thus, the pollutant load rather than the water flow determines the surface area in this case.

Since the septic tank has been designed for 20 persons, so will the wetland. If it proves to be too small, or if the use of the centro comunitario will change in such a way that the pollutant load increases, the width of the wetland may always be increased to meet new demands. The size of the wetland, following the most common recommendation of 2 m^2 $person^{-1}$, would thus be 40 m^2, which would mean that it would have a width of 2.7 m if the minimum length of 15 m is chosen. The relation between width and length does not have any significant impact on the treatment performance of the wetland (EPA, 1999).

Procasha has a positive attitude towards the idea of reusing the treated wastewater for irrigation of the cooperative's green area. The Procasha architect María Esther Soto has an idea for a system of perforated pipes shallowly buried in the ground, through which the treated water flows and infiltrates the ground at plant root level. To avoid the need for another pump, the outlet of the wetland would have to be located high enough for the water to flow through the system by gravity. This could be obtained by using the soil that is removed when excavating the wetland pit for constructing walls that allow the wetland surface to be located above the surrounding ground level, as long as the soil is compacted enough to keep the water within the wetland. The lot has a slight inclination to the east, which aggravates the project since the wetland is located to the southeast of the green area (see figure 7), and elevating the wetland would partly or fully neutralize the effects of the inclination.

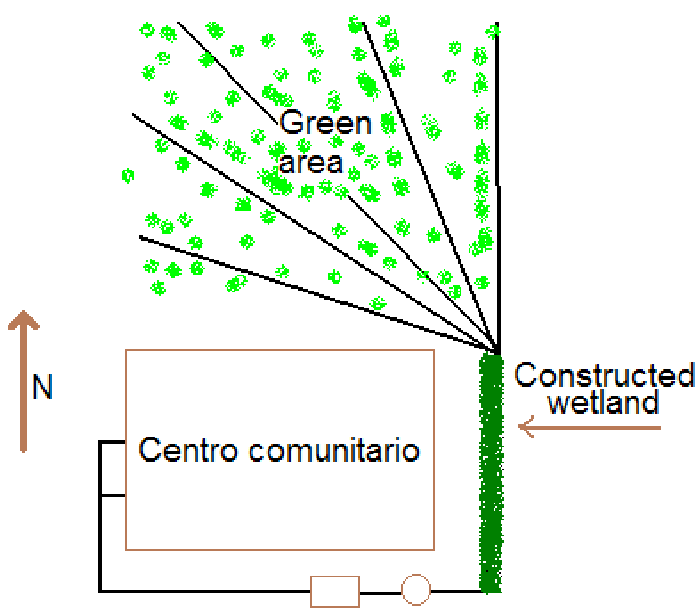


Figure 7. *After passing through the septic tank and the wetland, the treated wastewater could be led by underground perforated pipes to irrigate the plants of the cooperative's green area. Pipes are shown as black lines in the illustration.*

-Laboratory work

In order to find out whether a lining would be needed for a wetland, the saturated hydraulic conductivity of the soil at the proposed location was tested. Two tests were made at different spots a few meters from each other, one in the hole dug for an infiltration well besides the centro comunitario at a depth of 0.5 m, and another at the east side of the buildings, a few meters from the wall, at a depth of 0.7 m. The tests were performed at the laboratory of geotechnology at Chalmers University of Technology in Göteborg, Sweden, by Peter Hedborg. The test results show that the clayey silt has a saturated hydraulic conductivity of less than 10^{-8} m s^{-1} for densities that can be expected under undisturbed conditions (see appendix VI), thus fulfilling the criteria for substituting a waterproof lining for a constructed wetland (see section 4.2.5).

The upper soil layer of the lot has been observed to be very homogeneous. Three percolation tests have been performed by the architect Clara Liliana Arevalo Gonzales, earlier employed by Procasha, and she states (conversation 2010-05-28) that the results from the three locations within the lot were very similar to each other. Taking this into consideration, it is assumed that the two samples are representative of the upper soil layer at the location.

At no location the layer of clayey silt has been observed to be thinner than 0.9 m, and thus it is assumed to be deep enough throughout the area to hold the wetland (The US EPA (1999) recommends that if no lining is to be used, the impermeable soil layer should be at least 0.3 m thick under the wetland). If the layer proves to be too shallow at any spot, measures should be taken to prevent water from escaping.

-Cost

Although being unnecessarily big in this case, according to store staff, the pump mentioned in section 4.2.4 is the smallest pump available for handling wastewater. The cost for the wetland (not including the irrigation system mentioned above, which would according to the architect María Esther Soto anyhow be much cheaper to construct than the wetland) would then be at least US$ 560, including:

- US$ 330 for the pump,
- 1600 bolivianos (or about US$ 230) for the gravel, and
- an unknown cost for the plants, plastic tubes and a container for the pump

-Maintenance

If the wetland gets clogged, it has to be drained to allow cleaning of the media. Since most of the material accumulates in the first part of the wetland, though, it is likely that only that part of the wetland needs to be cleaned.

If surfacing occurs, maintenance is probably needed. In comparison to other treatment methods, constructed wetlands generally need little maintenance (Langergraber, 2005).

4.3 Water reuse for irrigation purposes

Water reuse is desirable wherever freshwater is a scarce resource. Throughout the world, reused wastewater constitutes an important resource for agricultural irrigation, irrigation of urban parks, flushing toilets and for other purposes. The quality of the reused wastewater varies substantially, and is often inferior, especially in developing countries. Wastewater reuse for the purpose of drinking or cooking is a more complex and costly process that will not be considered in this thesis.

In Cochabamba, water scarcity has enforced a widespread use of wastewater containing high levels of pathogens, heavy metals and salts in urban and peri-urban agriculture. The effluents of the municipal wastewater treatment plant are used extensively in the southern outskirts of Cochabamba, where farmers have an agreement with Semapa to access these waters (Huibers et al., 2004). However, due to overloading of the plant, the effluents are of inferior quality. The river Río Rocha, which is heavily contaminated by domestic and industrial wastewater (during the dry season to the extent that almost all of its flow is constituted by wastewater), is used extensively as a source for irrigation water (Huibers et al., 2004).

Soil degradation has enforced a switch to more salt-tolerable crops in some of the wastewater-irrigated areas (Huibers et al., 2004). One should keep in mind, though, that the groundwater of the valley often contains elevated amounts of salts from the beginning, which makes it non-optimal for irrigation (Moscoso and Coronado, 2002), and that excessive irrigation worsens the problems (Huibers et al., 2004).

Crops commonly cultivated in Cochabamba are alfalfa, fodder crops *(lolium sp.),* maize, potatoes and beans. However, salinisation has resulted in that many farmers have shifted to the salt-tolerable lolium, and some formerly cultivated land has been abandoned due to soil degradation. If managed properly, however, wastewater could constitute an important resource for the farmers of Cochabamba (Huibers et al., 2004).

In the case of COVIVIR, wastewater could be reused for irrigation purposes after receiving proper treatment, e.g. through the use of a constructed wetland. Care might need to be taken, though, to secure the quality of the reused water, depending on the crops and how they are to be used.

4.3.1 Norms and guidelines

For health protection reasons, wastewater reused for irrigation should be monitored to fulfill certain quality criteria, depending on what is irrigated. In table 1, the World Health Organization's guidelines for microbiological quality of reused water are shown. Since the wastewater of COVIVIR is to be generated through normal household activities, other contents that could be harmful to human health than those presented in the table will probably not be present, as could be the case for e.g. industrial wastewater.

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100ml[c])	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	≤ 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by irrigation technology but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

[d] A more stringent guideline limit (≤ 200 faecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Table 1. *WHO 1989 guidelines for the microbial quality of reused wastewater. Taken from Blumenthal et al. 2000.*

Recent literature suggests a more stringent approach regarding intestinal nematodes concentration (0.1 eggs per liter), while not recommending a changed approach towards the concentration of faecal coliforms (EPA, 2004b).

Making guidelines for irrigation water quality is difficult and will always be affected by a certain degree of arbitrariness. This is easily realized when looking at the guidelines of different states of the U.S.A., which vary significantly in all aspects between states (EPA, 2004b).

4.3.2 Parameters

-Metals

Metals in the municipal wastewater of Cochabamba constitute an important problem, as industries – defying strict regulations – release their toxic wastes into the sewerage system. This has lead to a buildup of heavy metals in soils, with very high concentrations of cadmium (Cd), chromium (Cr^{6+}), and lead (Pb) (Huibers et al., 2004). In the case of COVIVIR, though, metals should not be a problem since only domestic wastewater will be present (assuming that the soils are not already contaminated).

-Nutrients

Although nutrients are absolutely necessary for plants to be able to live, and an increased supply stimulates growth up to a certain level, too high supplies of N and P might give undesirable effects. Sensitive crops might be negatively affected by N concentrations bigger than 5 mg l^{-1} irrigation water, while most other crops have not proven to be adversely affected until the N concentration exceeds 30 mg l^{-1}. Many fruits, such as citrus, avocado and grape (the latter being a sensitive specie) show delayed maturity if excessively exposed to N, which leads to low yields, and many grain crops develop too weak stalks. Grapes in Libya have been observed to produce almost no fruit at all when irrigation water continuously contained more than 50 mg l^{-1} N. Excessive use of N for the cultivation of ruminant animal fodder may cause health problems for the animals. The sensibility varies with the growing stage – in early stages a high N concentration is often not harmful, while it should often be avoided later in the plant's life cycle. Maize, which is commonly cultivated in the Cochabamba region – likewise at fields adjacent to the lot – is one of the crops less sensitive to excess N (Ayers and Westcot, 1985).

-Pathogens

Pathogens are hazardous to human health and should therefore be avoided in agricultural irrigation. If the crops are not to be consumed raw, however, some pathogen content could be accepted, or in the case of e.g. fruit trees, as the fruit is protected from exposure through their elevation, as long as the water is applied at ground level.

-BOD

A 1992 study has shown that it is feasible to use water with a high BOD-level for irrigation in warm climates, but that it could have some adverse effects in cold climates (Nashikkar, 1992).

4.4 Dry toilets

The dry toilet is a urine separating composting toilet which does not use water for flushing. Dry toilets offer a very ecological solution mainly for two reasons:

1. water is saved, and
2. nutrients are reused.

Also, contamination is avoided, which might be more or less important depending on what other options are at hand, and the properties of the surrounding environment.

Initial costs vary widely, but in comparison to the costs of installing a septic system, dry toilets are generally a less costly option. However, since the septic system of COVIVIR would be shared between several households, it is uncertain which option would be the least costly, especially considering that costs may vary significantly between different types of dry toilets. However, the Cochabamba-located organization Aguatuya has a program in which they economically and practically help low-income households in peri-urban areas installing composting toilets with urine separation. The materials as well as instructions are provided by Aguatuya; the only thing that has to be provided by the final users is labor. According to Graciela Landaeta, the cooperative is definitely located in a peri-urban area, and should therefore fulfill the conditions for being a candidate for the support. Aguatuya staff have visited the site of COVIVIR and claims that they probably would approve funding.

In Bolivian legislation, a distinction is made between urban and rural land, and in order to receive the funding, the dwellings have to be located at land classified as urban (Encalada, interview 2010-05-11). At the moment, the lot of COVIVIR is located at land classified as rural, but according to Hernán Aranda at the Procasha Foundation, there should not be any problem in getting this classification changed through an application to the municipality of Sipe Sipe. Aguatuya, like Procasha, receives funding from The Swedish Cooperative Center, which could facilitate cooperation between the two organizations.

Maintenance can be expected to be higher for dry toilets than if a septic syatem with or without a wetland is installed; the composting toilets need to regularly be emptied and their contents handled. Folders with instructions for construction and maintenance are provided by Aguatuya, and can be found on their web-page at: http://www.aguatuya.watsan.net/page/231.

The dry toilets that Aguatuya use could, at any point in their lifetime, easily be converted to conventional water toilets, should public sewers be installed in the area in the future (Marcelo Encalada, 2010-05-11).

4.4.1 Urine as a resource

While constituting less than one percent of the domestic wastewater, urine accounts for about 80% of its nitrogen content, 55% of its phosphorous content, and 60% of its potassium content, which can make it, if collected, a relatively concentrated fertilizer. Pathogens do generally not constitute a significant risk to human health when urine is used as a fertilizer (Schönning, 2002).

Urine is sterile in the urine bladder of a healthy person. However, while transported out of the body it picks up bacteria, and it might also be contaminated through for example fecal cross-contamination, as feces may be miss-placed in the urine section of the toilet (Schönning, 2002). Storage of urine in a tank is an effective method of killing pathogens. Caroline Schönning (2002) has developed guidelines for storing times under different conditions for urine that is to be used for different crop categories, see table 2.

After storage, the urine could be spread without dilution during rainy season or before irrigation, but Aguatuya recommends that each liter of urine should preferably be diluted with 3 to 10 liters of water before application.

Storage temperature	Storage time	Possible pathogens in the urine mixture	Recommended crops
4°C	≥1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	≥6 months	Viruses	Food crops that are to be processed, fodder crops[c]
20°C	≥1 month	Viruses	Food crops that are to be processed, fodder crops[c]
20°C	≥6 months	Probably none	All crops[d]

[a]Gram-positive bacteria and spore-forming bacteria are not included.
[b]A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.
[c]Not grasslands for production of fodder. Use of straw is also discouraged.
[d]For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

Table 2, adapted from Shönning, 2002. *Relationship between storage conditions, pathogen content[a] of the urine mixture and recommended crop for larger systems[b]. It is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g l^{-1}.*

4.4.2 Feces as a resource

Feces contain smaller amounts of nutrients than urine, and due to high pathogen contents they contribute greater health risks. For health protection reasons, feces should be stored during a time period no shorter than 12 months (for Cochabamba conditions) so that they decompose and turn into soil. After being applied at the cultivation site, the soil should be covered with a 10 to 20 cm thick layer of other soils, to prevent the dispersion of pathogens that might still be present (Aguatuya, 2008).

4.5 Field work

Two percolation tests were performed, investigating soil percolation rates. Slightly different methods were used at the two occasions, as a result of one specific and well-described method being recommended in the literature for the second test. For the first test, a method described by the engineer Julio Rodriguez Humerez, earlier consulted by Procasha, was used.

4.5.1 Percolation test at the site of the prospective seepage pit for the centro comunitario

A percolation test, with the purpose of investigating the prerequisites for soil infiltration of wastewater, was performed 2010-04-15 at the bottom of the excavation that has been dug for the seepage pit next to the centro communitario (see figure 3). The results give at hand that the diamicton layer has a permeability that is sufficient for infiltration of wastewater. An earlier percolation test performed by the then Procasha architect Liliana Arevalo Gonzales (before the excavation was dug) has shown that the upper layer of clayey silt has a very low conductivity; the results, however, have unfortunately been lost, but according to Arevalo Gonzales the percolation rates of the three spots included in the test were very similar, which indicates that the upper soil layer is quite homogeneous.

The percolation test (the first one mentioned above) was performed in a hole with a depth of 50 cm and a cross-section, seen from above, of 30x30 cm (i.e. quadratic). Since the conditions, as they would be with a septic system in operation, should be imitated, the soil must be saturated with water before percolation tests are performed. The day before the test, the hole was filled with water three times, that was left to infiltrate the soil, for the soil particles to be allowed to swell, decreasing the soil's permeability. This step is very important, since the soil is constantly soaked beneath an infiltration system in use (EPA, 1980).

For the actual test, the hole was filled with water, and the level of the water table was measured every two minutes. The data as shown in table 3 were obtained.

Time: (minutes)	0	2	4	6	8	10	12	14	16
Level: (cm)	32	28	26	25.0	23.9	22.9	22.0	21.1	20.0

18	20	22	24	26	28	30	32	34	36
19.1	18.2	18.0	17.2	16.6	16.0	15.4	15.0	14.5	14.0

38	40	42	44	46
13.5	12.8	12.4	11.8	11.2

Table 3. *Observed water levels as a function of the time passed.*

This data give a percolation rate of 0.27 cm minute^{-1} (or 3.75 minutes cm^{-1}) using the mean of the three last values (the test was interrupted after the rate at which the water level was sinking had stabilized). These numbers should be used with caution, though; percolation rates might vary with different shapes of the hole, and also depends on the water level. Moreover, a 10 cm thick layer of clayey silt was found when digging the hole (see figure 2), which must have affected the result (to the safe side though, since fine-grained soils are more impermeable than coarser soils). The results might give an idea, though, about the ability of the soil to receive the septic tank effluents. Since the percolation rate is considerably faster than the slowest values recommended for leach fields (see section 4.1.1), the diamicton layer is doubtlessly permeable enough for wastewater infiltration.

4.5.2 Percolation test for evaluating the prerequisites for a leach field

A percolation test was performed, using a method recommended by the U.S. Environmental Protection Agency (EPA, 1980), just by the eastern wall of the centro comunitario. The purpose of the test was to investigate the prerequisites for infiltration of wastewater through a leach field (see section 4.1.1).

A square hole was dug, 70 cm deep and with a 15x15 cm cross-section seen from above (i.e. quadratic). The hole was pre-soaked the day before the test to allow soil particles to swell (if the soil would not be pre-soaked, inaccurate results would be obtained, as described in section 4.5.1); a water level of 40 to 70 cm above the bottom was maintained for about 5 hours, and then the hole was left filled with water over night. When the test started the next day, water was still present in the hole to a depth of about 10 cm.

The hole was filled with water to a depth of 33 cm, and the water level was measured every 30 minutes. After every measurement, water level was restored to 33 cm. According to the recommendations, the test may be considered finished when a measurement do not differ by more than 0.2 cm from anyone of the two previous ones. The data as shown in table 4 were obtained.

Time (min):	30	60	90	120	150	180
Drop (cm):	4.1	3.2	2.7	2.8	2.7	2.6

Table 4. *The drop of the water table was measured every 30 minutes, after which the water table was restored to a certain level*.

This gives a percolation rate of 0.09 cm minute^{-1} (or 11 minutes cm^{-1}) using the mean value of the last three drops. This value is within the recommendations for what is acceptable where a leach field is planned (see section 4.1.1), although faster rates would be preferable for practical reasons (i.e., a smaller area would be required to absorb the water if the percolation rate is faster).

Normally, it is recommended that at least three tests be performed at different spots in the area, since soil characteristics may differ significantly within a small area. However, the upper clayey silt layer of the lot has been observed to be very homogeneous, and thus it was decided that only one spot needed to be tested.

4.6 Conclusions and recommendations

4.6.1 Recommendations for the centro comunitario

Dry toilets are a great solution for avoiding heavily contaminated wastewater, but they demand maintenance. According to Marcelo Encalada at Aguatuya, they are not suited for buildings that are used commonly, since maintenance will frequently be neglected if the responsibility is not in the hands of one certain household. Therefore, he strongly advices against using dry toilets for the centro comunitario. Moreover, the construction of a system for water toilets has already begun at the centro comunitario.

A seepage pit is not recommendable due to the fact that it would concentrate all the pollution at one small spot; authorities worldwide, for that reason, generally do not recommend seepage pits.

A leach field could be used, since the permeabilities of the soils seem to be sufficiently high. However, a quite large area would probably be needed, which would make the implementation more costly and complicated than if more permeable soils were available.

The method that would be best from a security and water preservation perspective, and would also add aesthetical value to the lot, would be a constructed wetland. It avoids the risk of contaminating the groundwater, at the same time as it allows for the reuse of water for irrigation. It is, however, also the most costly alternative, although being a relatively cheap method for wastewater treatment.

Recommendation: A septic tank followed by a constructed wetland is recommended (built according to instructions in section 4.2.6). At second hand, if a constructed wetland is found to be too expensive or not desirable for any other reason, a sufficiently large leach field is recommended (together with a septic tank).

4.6.2 Recommendations for the dwelling houses

Dry toilets are strongly recommendable for the dwelling houses. Through their use, wastewater is avoided, and with the economic and practical support of Aguatuya they offer a cheap and convenient solution.

If, however, water toilets are to be used, it is strongly recommended that high-efficiency toilets be installed, which use significantly less water per flush, and also offer the opportunity to use less water when flushing urine than feces by having two different buttons, one for each case. If water toilets are implemented, a constructed wetland would be preferable because of the proximity to the well and the massive wastewater load of 26 households.

Recommendation: Dry toilets provided by the Cochabamba located foundation Aguatuya are strongly recommended.

5. Risks

Several risks of varying character and magnitude, mainly related to health concerns, are involved when making use of the systems described in the earlier chapters. Risks may be imposed by phenomena beyond the control of COVIVIR, as well as by the cooperativists' own activities. In this chapter, risks are identified and described, and measures to reduce them are proposed.

5.1 Flooding

The rivers often flood during the period January to Mars, due to heavy raining (H. Alcaldía municipal de Sipe Sipe, s 20). Any flooding poses a risk to conventional septic systems since the soil absorption area should remain unsaturated (see chapter 4).

The cooperative is located in between two rivers, with a distance of about 300 meters to each one of them. The flows of the rivers are very irregular, and they often flood after heavy rains. Although the area is rather flat, however, the site of the cooperative is not subject to high risk of flooding – a couple of hundred meters further downstream the risk is more immediate (Ala Quiroz, 2010).

5.2 Contamination of water sources

Waterborne disease is one of the great health issues of the world today, with diarrheal diseases causing millions of deaths every year. Apart from pathogens, chemical substances might pose a risk. Several possible sources of contamination are located in the area, among them poultry and pig farms, slaughterhouses, septic systems and illegal drug factories.

Further away, in Quillacollo about 10 kilometers from Sipe Sipe, industries of various kinds are located, producing for example beverages, leather, paper, and chemicals such as soap and plastics (Maldonado et al. 1998). The wastewaters of these industries do normally not undergo sufficient treatment (Duran, interview 2010-05-13).

According to the hydrological engineer Mauricio Solis, who has a seven-year long experience working at the well-drilling Cochabamba company Hidro Drill, the risk of contamination of the drinking water is low if the well is deep enough, since normally only the shallow aquifers are contaminated by human activity. Solis claims that the two largest risk sources of contamination of the deeper aquifers are illegal cocaine factories located in the surrounding mountains, which use harmful chemicals in their production (the water infiltrating the deeper aquifers mainly comes from the mountains, through cracks in the rock or along the limiting area between rock and soils), and abandoned wells which offer an opportunity for pollutions to enter directly into the deeper aquifers, thus getting by the clay-layers that otherwise protect them. Risk of contamination also occurs if the well is over-exploited, since that could make water from shallow polluted aquifers penetrate the protecting layers of clay (Solis, interview 2010-05-12).

At many locations in South America, chemical waste from cocaine production has had damaging effects on the environment. Kerosene, sulfuric acid, lime, calcium carbide, acetone, toluene, and ethyl ether are dumped on the ground or into rivers, posing health risks to local people (Trade and Environment Database, 2010-09-05).

5.3 Depletion of water resources

Even though groundwater levels until now have not been observed to sink even though exploitation has increased, one must consider the risk of future scarcity. Factors that could affect the groundwater table include increased population, changed water consumption patterns, or changed precipitation patterns. Climate change could affect precipitation, even though the effects that a future temperature increase might have on precipitation patterns are very uncertain (Magrin et al., 2007).

According to the hydrological engineer Mauricio Solis at the Cochabamba well-drilling company Hidro Drill, the groundwater resources of Sipe Sipe are so abundant that the risk of scarcity within reasonable time is very low; the recharge of the aquifers that are located at an adequate depth is large due to the proximity to the mountains. The flow rates of the wells located in Sipe Sipe, Solis claims, are the highest in the whole of Cochabamba (Solis, interview 2010-05-13).

5.4 Frost

Solar water heaters that have no anti-freezing system are sensible to sub-zero temperatures. Although Sico sol offers solar water heaters equipped with anti-freezing systems, the company does not recommend such a system for the area in question, since the minimum temperatures are high enough throughout the year (Astete, interview 2010-05).

5.5 Risks of social character

Conflicts regarding water resources are not uncommon in the area, and the laws are not applied to the extent as could be expected in more developed regions. An OTB could suddenly and arbitrarily, without risking legal actions, shut down water supply for an affiliate who has invested relatively large amount of money in connecting to its well (Solis, interview 2010-05-11). Besides suffering the same risks as would be the case if COVIVIR had its own well, the alternative of affiliating to the OTB Convento's well thus also offers risks of a more social character. The severe problems of collaboration that have existed in the contacts between the OTB Convento on the one hand, and Procasha and the cooperativists of COVIVIR on the other, gives a hint on the risk of future tensions, which might lead to conflicts in which COVIVIR is likely to pull the shortest straw since they are in no power to keep the water running through the pipes operated by the OTB without the intervention of authorities.

On the other hand, OTBs have been reported to forcibly intervene in well-drilling projects that are to be performed within their territory (but on land owned by others), for example by blocking roads to prevent machinery from arriving, even though no legal obstacle exists against someone drilling a well at their own property. Authorities, especially in rural areas, are according to Mauricio Soles generally not too willing to intervene in such conflicts. These conditions have led to well-drillers having to pay money to OTBs to be able to drill their wells (Solis, interview 2010-05-11). According to Soles, it is obvious that economic factors are the reason behind these OTBs' behavior – the alternative to drilling a well is often to affiliate to an OTB's well at a high cost (or to use expensive and inconvenient tank trucks).

5.6 Conclusions and recommendations

It is not easy to protect oneself from all the risks that might be present. Testing water quality costs money and cannot be done too often, and contamination may come sudden. Preventing depletion of water resources is beyond the power of COVIVIR. One way of reducing the risks is to choose a safe way of disposing the wastewater generated within COVIVIR, thus avoiding causing contamination of the groundwater. Please see chapter 4 for wastewater treatment solutions.

Disinfecting the water that is to be consumed is a simple and effective way of reducing risks to human health. Please see section 3.3 for cheap and environmentally friendly methods for water disinfection.

6. Other recommendations

According to Graciela Landaeta, it is an ambition of Procasha that COVIVIR be an environmentally friendly neighborhood. Although it might be somewhat off-topic in a report that focuses on water issues, I therefore include some recommendations regarding household garbage treatment in this thesis, since garbage production is one of the major factors that determine the typical household's total environmental impact.

Reuse and recycling are fundamental elements in a sustainable society, since they prevent unnecessary raw material extraction and energy consumption. It is therefore highly relevant that as much as possible of the material discarded by the cooperativists be put back into circulation rather than ending up at Cochabamba's growing and malfunctioning landfill of Kara Kara. Glass and paper could be collected and sold to companies located in central Cochabamba, and perhaps also in Sipe Sipe. At one recycling company (which according to the owner does not yet have a name, but that is located at Ladislao Cabrera 0446 in Cochabamba) the prices of some common residual materials, on the 14th of may 2010, where:

Paper (of the type that is used for books, printers and such): 1 boliviano per kilo
Paper (newspapers): 0.50 bolivianos per kilo
Cardboard: 0.20 bolivianos per kilo
Glass (colored): 0.10 bolivianos per kilo
Glass (uncolored): 0.30 bolivianos per kilo
Plastic bottles (and their soft plastic wrapping): 0.60 bolivianos per kilo
Aluminium: 4 bolivianos per kilo
Cupper: 30 bolivianos per kilo
(one boliviano equals about 0.1€)

Whilst the prices of aluminum and copper may vary significantly over time, the prices of the other materials are normally rather stable according to the company owner. If containers are set up at COVIVIR's lot, where the families can place their recyclable materials to be brought for sale when the containers are full, an easily maintained system for economic and environmental benefits has been established.

A compost could also be set up at the lot, for organic household waste management reusing the nutritional contents of organic waste. The soil produced could be sold or donated to nearby farmers. This would imply environmental benefits as the need for fertilizers would be reduced, and a practical as well as an environmental benefit as the need for garbage transportation and treatment would be reduced.

7. General discussion

In this thesis, I have attempted to use the theory of my civil engineering bachelor field combined with the theory of my master field, industrial ecology, to identify and evaluate options for water supply and wastewater treatment with a focus on sustainability, for a 26 household housing cooperative in Cochabamba, Bolivia. The work has resulted in a set of recommendations, specified and motivated at the end of chapters 2, 3 and 4, and listed together in chapter 8, Conclusions.

Identifying options always implies the risk of missing out on some possible solution that could have been important to consider. In order to find every possible option that could be of relevance, I have studied recent literature with a broad scope on environmentally friendly solutions for household water and wastewater, e.g. Franken, 2007, thus minimizing the risk of missing out on any important technology. I have also talked to local experts on water issues.

Deciding upon the recommendations has been more or less difficult; in some cases, it has been rather obvious what the final recommendation would be (e.g., in the case of the dry toilets), but in others, uncertainties or conflicting interests have made it harder to state what would be the best alternative. Conflicting interests could be those between economy, ecology or health concerns, or even between different ecological aspects (e.g., a constructed wetland consumes more energy than a seepage pit, but emits cleaner effluent water).

The construction at the lot of COVIVIR has continued since my fieldwork was carried out, and therefore, at the completion of this thesis, some descriptions of the situation might be out of date. I have been in contact with Procasha staff, though, to ensure that no facts have changed or emerged that would affect the conclusions of this thesis.

In the next chapter, the recommendations from earlier chapters are brought together. Those are the options that I have found to be the most appropriate, balancing social, economic and environmental aspects. Hereby, by turning them over to Procasha and COVIVIR, my work is finished, and I can do no more than to hope for that my advices have been helpful.

8. Conclusions

In this final chapter, the main conclusions of the project, i.e. the recommendations, are brought together, and grouped according to their relevancies. While some solutions are strongly recommended, other recommendations are less accentuated; this might be due to uncertainties, conflicting interests, or to more than one option being relatively equivalent.

Below, the solutions for water and wastewater systems recommended in this thesis are listed in two groups, depending on how strongly they are recommended. The order of appearance within the groups does not indicate any difference in the degree to which a solution is recommended.

Strong recommendations

The local groundwater should doubtlessly be used (although not from the most shallow aquifers for potable purposes, since they might be contaminated).

Solar water heaters are strongly recommended to provide hot water.

Dry toilets provided by the Cochabamba located foundation Aguatuya are strongly recommended.

Water-efficient equipment for kitchens and bathrooms, e.g. high-efficiency shower heads and taps, are recommended. If water is to be disinfected, it is recommended that UV disinfection or solar pasteurization be used instead of the more common method of boiling the water on the stove, which is quite energy consuming.

Less accentuated recommendations

Given the information that is currently available, it is recommended that COVIVIR should affiliate to the nearby well operated and owned by the OTB Convento.

A septic tank followed by a constructed wetland is recommended (built according to instructions in section 4.2.6). At second hand, if a constructed wetland is found to be too expensive or not desirable for any other reason, a sufficiently large leach field is recommended (together with a septic tank).

References:

Andersson, A-C, O Andersson and G Gustafson (1984): *BRUNNAR. Undersökning-Dimensionering-Borrning-Drift.* BFR Rapport R42:1984.

Aguatuya (2008): *Manual del usuario: baños secos ecológicos*. Fundación Aguatuya, Cochabamba, Bolivia.

Ala Quiroz, Norma Louisa (2010): *Análisis y zonificación de riesgos naturals en el Municipio de Sipe Sipe – Bolivia.* Proyecto de Grado de Licenciatura en Ingeniería Ambiental, Universidad Católica Boliviana "San Pablo", Cochabamba, Bolivia.

Asif, M. and T. Muneer (2007): *Solar Water Heating: Domestic and Industrial Applications.* Encyclopedia of Environmental Science and Engineering, Fifth Edition.

Ayers, R.S. and D.W. Westcot (1985): *Water quality for agriculture.* Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/003/t0234e/t0234e00.htm

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe): http://www.bgr.bund.de/cln_144/nn_324520/EN/Themen/Wasser/Projekte/TZ/TZ__Bolivia/cabas__fb__01__en.html

Blumenthal, Ursula J., D. Duncan Mara, Anne Peasey, Guillermo Ruiz-Palacios and Rebecca Stott (2000): *Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines*. Bulletin of the World Health Organization. http://whqlibdoc.who.int/bulletin/2000/Number%209/78%289%291104-1116.pdf

CGIAB (Comisión para la Gestión Integral del Agua en Bolivia) (2009): *Justicia Ambiental y Sustentabilidad Hídrica.*
CGIAB: http://www.aguabolivia.org/situacionaguaX/SituacionX/CUENCACOCHABAMBA.htm

Cordesius, Helena and Sofian Hedström (2009): *A Feasibility Study on Sustainable Wastewater Treatment Using Constructed Wetlands - An Example from Cochabamba, Bolivia.* Master thesis, Lund University, Sweden.

Davis, Louis (1994): *A handbook to constructed wetlands.* USDA - Natural Resources Conservation Service, and the US Environmental Protection Agency.

EPA (1980): *Design Manual – Onsite Wastewater Treatment and Disposal Systems*. United States Environmental Protection Agency, Office of Water Program Operations, Washington DC.

EPA (1999): *Manual – Constructed Wetlands Treatment of Municipal Wastewater.* United States Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio.

EPA (2004a): *Constructed Treatment Wetlands.* United States Environmental Protection Agency, Office of Water.

EPA (2004b): *Guidelines for Water Reuse.* United States Environmental Protection Agency. http://www.epa.gov/NRMRL/pubs/625r04108/625r04108.htm

Franken, Margot (2007): *Gestión de aguas – Conceptos para el Nuevo milenio.* Universidad Mayor de San Andrés, Instituto de Ecología, La Paz, Bolivia.

H. Alcaldía municipal de Sipe Sipe (2006-2010): *Diagnostico del Municipio de Sipe Sipe.*

HarvestH2o.com (2010-06-29): http://www.harvesth2o.com/faq.shtml#4

Huibers, Frans P., Oscar Moscoso, Alfredo Durán and Jules B. van Lier (2004): *The Use of Wastewater in Cochabamba, Bolivia: A Degrading Environment*. Wastewater use in Irrigated Agriculture – Confronting the Livelihood and Environmental Issues. CABI Publishing. http://www.crdi.ca/fr/ev-31595-201-1-DO_TOPIC.html

IRCSA (2010-06-29): http://www.ircsa.org/factsheets/lowincome.htm. International Rainwater Catchment Systems Association.

Jahani, Hamid R. (2005): Resistivity Methods. Water Encyclopedia. Ed. Jay H. Lehr and Jack Keeley. Vol. 5: *Ground Water*. Hoboken, NJ: Wiley, 2005. p443-448.

Landaeta, Graciela (2004): *Living in Unauthorized Settlements – Housing Improvement and Social Participation in Bolivia.* PhD Theisis, Lund University, Sweden.

Langergraber, Guenter (2005): *Constructed Wetlands.* Water Encyclopedia. Ed. Jay H. Lehr and Jack Keeley. Vol. 1: Domestic, Municipal, and Industrial Water Supply and Waste Disposal. Hoboken, NJ: Wiley, 2005. 892-897. *Gale Virtual Reference Library*. Web. 20 Apr. 2010.

Ledo, Carmen (2009): *El agua nuestra de cada día.* Universidad Mayor de San Simón, Cochabamba, Bolivia.

Lema, Ana María, Gizel Caballero, Roberto Ibargüen, Hebert Ayreyu (2001): *De la huella al impacto. La Participación Popular en municipios con población indígena.* Fundación Pieb, La Paz, Bolivia. (Available through Google Books.)

Magrin, G., C. Gay García, D. Cruz Choque, J.C. Giménez, A.R. Moreno, G.J. Nagy, C. Nobre and A. Villamizar (2007): *Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 581-615.

Maldonado, Mabel; Paul Van Damme and J. Rojas (1998): *Contamination and Eutrofization in Río Rocha Basin.* Rev. Bol. de Ecol. 3:3-9, 1998.

Mayer, Peter W, and William B DeOreo: *Residential End Uses of Water*. Aquacraft, Inc. Water Engineering and Management. American Water Works Association. 1998. p. 94.

Moreno, Cecilia, Neda Farahbakhshazad and Gregory M. Morrison (2000): Ammonia Removal from Oil Refinery Effluent in Vertical Upflow Macrophyte Column Systems.

Moscoso Agreda, Oscar, and Olver Coronado Rocha (2002): *Estudio complementario del caso Cochabamba, Bolivia.* Universidad Mayor de San Simón, Centro de Aguas y Saneamiento Ambiental, Cochabamba, Bolivia.

Muneer, T (2006): *Life cycle assessment of built-in-storage solar water heaters in Pakistan.* BUILDING SERV ENG RES TECHNOL February 2006 vol. 27 no. 1 63-69.

Nashikkar, V.J. (1992): *Effect of Reuse of High-BOD Wastewaters for Crop Irrigation on Soil Nitrification.* Environmental International, Vol 19, pp 63-69, 1993.

Naeumann-Redlin, S. Chr. Renner and J. Torres (2000): *Hidrogeología del Valle Central de Cochabamba, Bolivia.*- Proc. of the 1. Joint World Congress on Groundwater, Fortaleza, Ceará, Brasil, July 31 - August 04, 2000.

República de Bolivia, Ministerio de Desarollo Humano, Secretaria Nacional de Asuntos Urbanos (1994): *Reglamento nacional de instalaciones sanitarias domiciliarias.* La Paz, Bolivia.

Rosén, L., P. Hokstad, A. Lindhe, S. Sklet,J. Røstum (2007). Generic Framework and Methods for Integrated Risk Management in Water Safety Plans. TECHNEAU, 2007.

Salvato, Joseph A., Nelson Leonard Nemerow and Franklin J. Agardy (2003): *Environmental Engineering*. John Wiley & Sons, Inc., Hoboken, New Jersey.

Schönning, Caroline (2002): *Evaluation of microbial health risks associated with the reuse of source separated human urine.* Swedish Institute for Infectious Disease Control.

Shultz, Jim and Melissa Crane Draper (2009): *Dignity and Defiance – Stories from Bolivia's Challenge to Globalization*. University of California Press.

Solana, Amy and Kate McMordie Stoughton (2007): *Water-Using Equipment: Domestic.* Encyclopedia of Energy Engineering and Technology.

Spångberg, Johanna and Johan Söderblom (2008): *Nutrient removal of domestic waste water in constructed wetlands in Cochabamba, Bolivia.* Master thesis, Uppsala University, Sweden.

Trade and Environment Database (2010-09-05): http://www1.american.edu/TED/coca.htm. American University, Washington D.C., USA.

The World Bank (2010-09-05): http://info.worldbank.org/etools/lacelectricity/countryscorecard.asp?country_id=4&gr1=1&selline=

UNDP, 2009: *Human Development Report 2009.*

UDAPE: http://www.udape.gov.bo/dossierRRNN/htms/doss0302.htm

Washington State University: http://cru.cahe.wsu.edu/CEPublications/eb1475/eb1475.html

WHO (2004): Sulfate in Drinking-water. World Health Organization. WHO/SDE/WHS/03.04/114.

WHO (2005): *Water Safety Plans.* World Health Organization, Geneva, Switzerland.

WHO (2008): *Drinking-water Quality, third edition.* World Health Organization, Geneva, Switzerland.

Persons:

Abasto, Cresencio. President of the OTB Convento, Municipality of Sipe Sipe, Bolivia.

Aranda, Hernán. Social worker at Procasha, Cochabamba, Bolivia.

Arevalo Gonzales, Clara Liliana. Architect formerly employed by Procasha, Cochabamba, Bolivia.

Astete, Rodolfo. Manager at the company Sico sol, Cochabamba, Bolivia.

Duran, Alfredo. Agricultural engineer, Centro Agua, Faculty of Agronomy (facultad de agronomía), Universidad Mayor de San Simón, Cochabamba, Bolivia.

Heredia, Jorge. Consultant engineer at the company Proyectos de Ingeniería, Cochabamba, Bolivia.

Landaeta, Graciela. Head manager of the Procasha foundation, Cochabamba, Bolivia (directora de la fundación Procasha).

Loma, Benjamin. Responsible for basic services (encargado de servicios básicos) at the municipality of Sipe Sipe, Bolivia.

Montaño, Rosario. Lic. M. Sc. Docente y investigador en Centro de Aguas y Saneamiento Ambiental (C.A.S.A.), Universidad Mayor de San Simón, Cochabamba, Bolivia.

Morales Requena, Nestor. Ingeniero. Jefe, Depertamento de operaciones (pertenecente a Gerencia de operaciones), Semapa, Cochabamba, Bolivia.

Müsch, Martha. Environmental engineer and manager of Environmental Management at the municipality of Cochabamba (ingeniera ambiental, directora de Gestión Ambiental del Alcaldía de Cochabamba).

Rodriguez Humerez, Julio. Consultant engineer at the company Proyectos de Ingeniería, Cochabamba, Bolivia.

Saravia, Dionicio. Lawyer at the firm Recursos Jurídicos, Calle Jordán 617, Cochabamba, Bolivia.

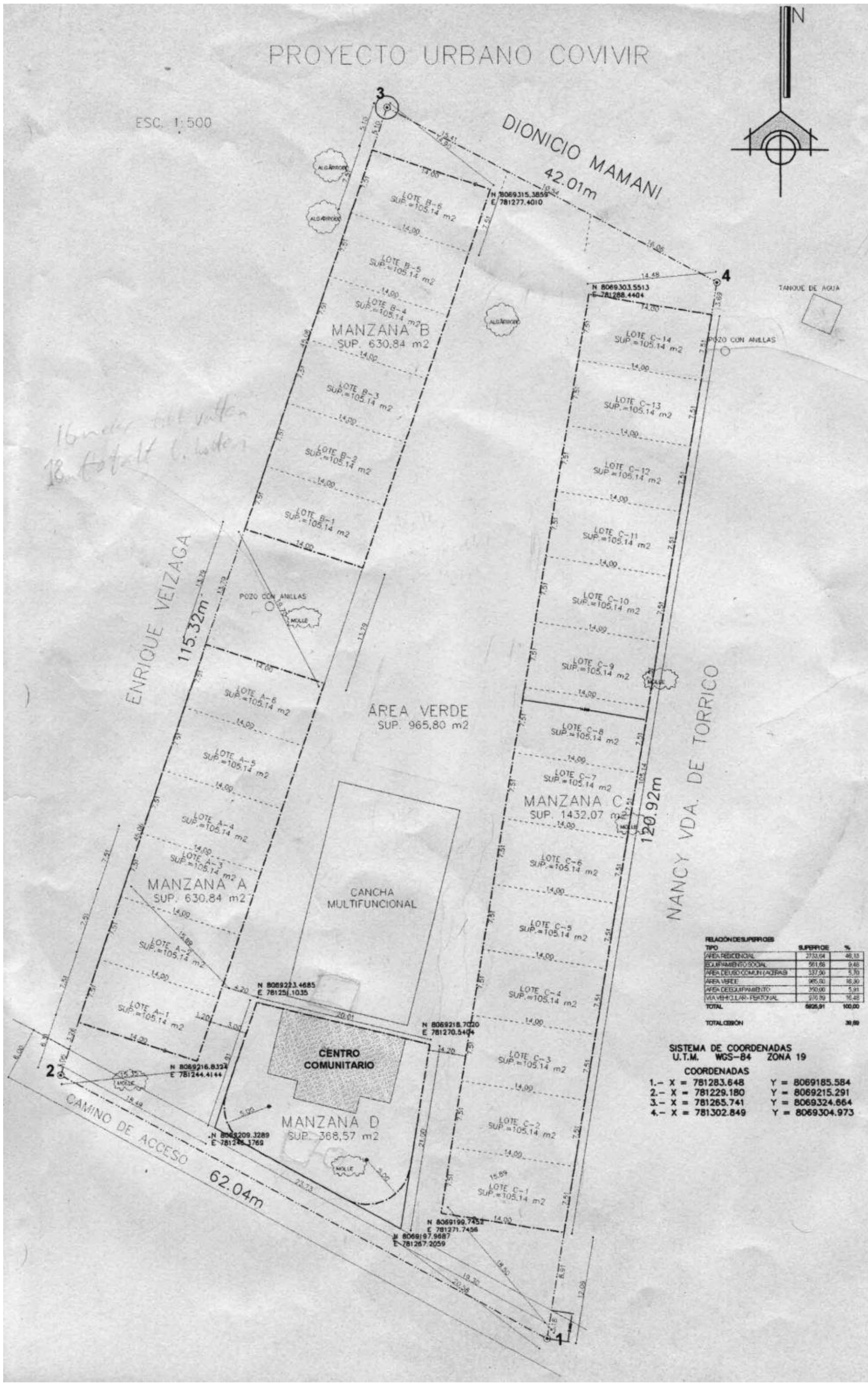
Solis, Mauricio. Hydrological engineer since seven years at the company Hidro Drill, Cochabamba, Bolivia.

Soto, María Esther. Architect at Procasha, Cochabamba, Bolivia.

APPENDICES

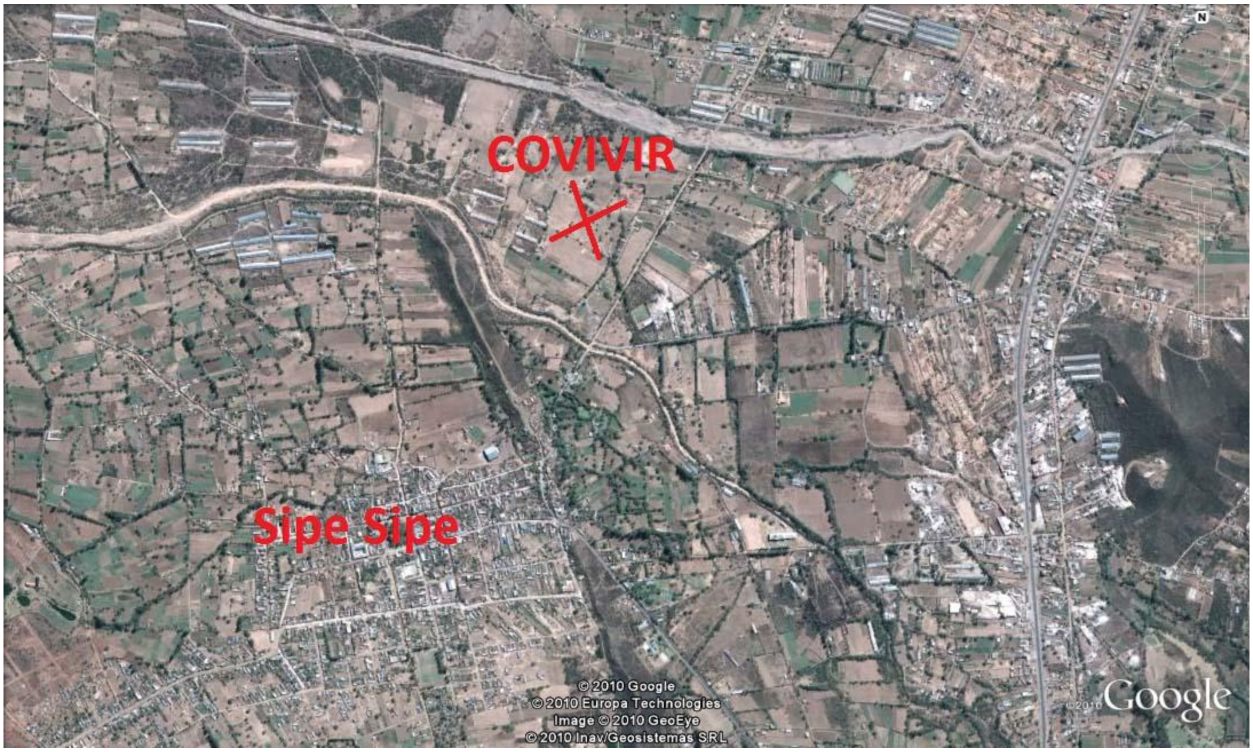
Appendix I

Plan of the housing area



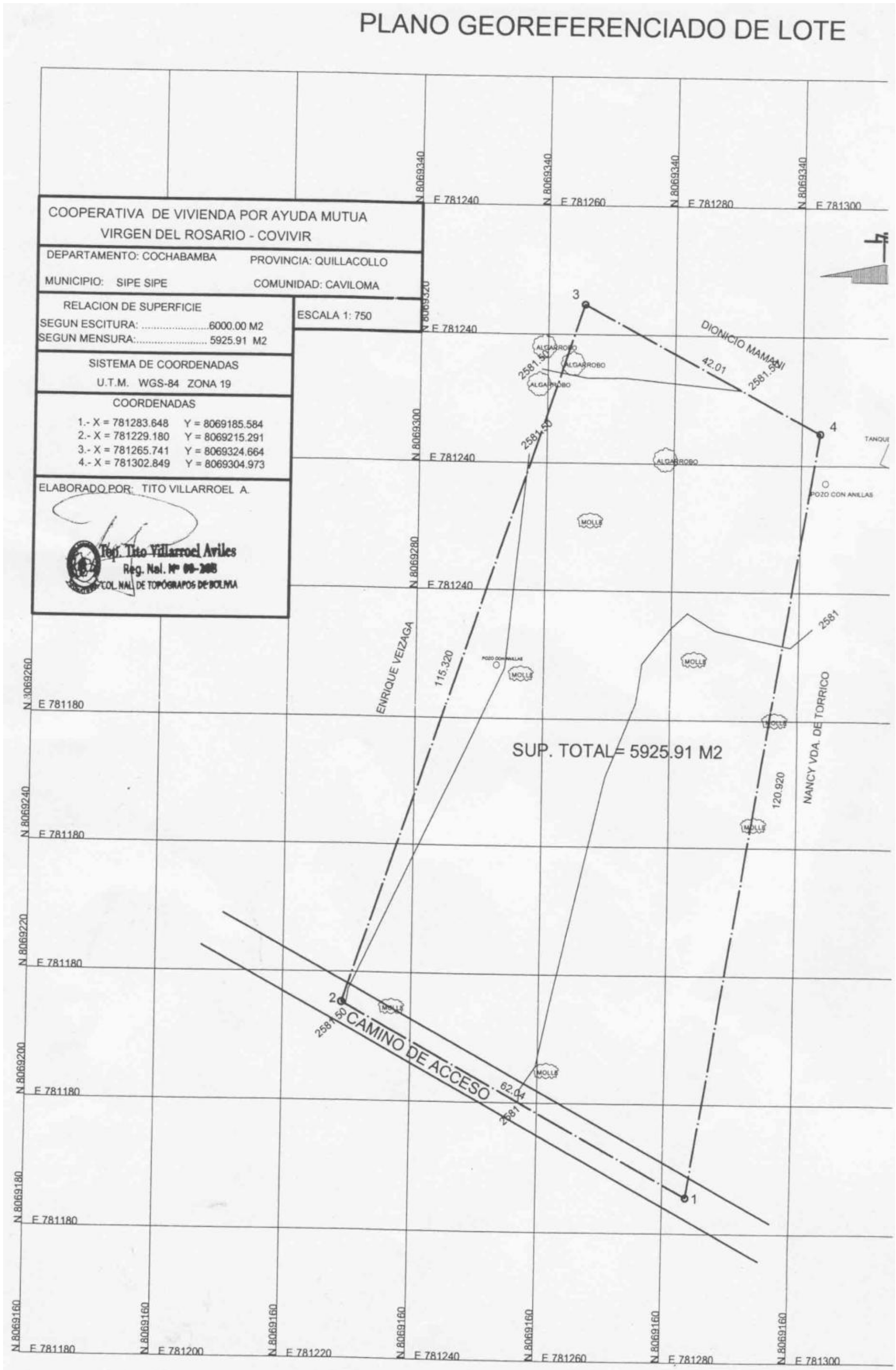
Appendix II

Map over the conurbation Sipe Sipe, with COVIVIR's construction site market out by a red cross



Appendix III

Plan of the lot of COVIVIR with contour lines (i.e. lines showing the elevation above sea level)



Appendix IV

Test results of water from the OTB's well, performed at the laboratory of C.A.S.A.

UNIVERSIDAD MAYOR DE SAN SIMON
FACULTAD DE CIENCIAS Y TECNOLOGIA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

CASA

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ENSAYO FISICOQUÍMICO MATRIZ AGUA

NUMERO DE REGISTRO:29209 -SC-21119
NUMERO DE MUESTRA:700 /10

PRESTATARIO : FUNDACION PROCASHA
DIRECCION - TELEFONO : OTB CONVENTO MOLLE MOLLE

DATOS DE LA MUESTRA:
DEPARTAMENTO : COCHABAMBA
PROVINCIA : CAPINOTA
LOCALIDAD : MUNICIPIO SIPE SIPE
TIPO DE FUENTE : POZO PERFORADO 85 m.
PUNTO DE MUESTREO : GRIFO
LUGAR DE MUESTREO : PATIO
PRESERVADA : SI
APARIENCIA : CLARA
TIPO DE ENSAYO : BASICO
MUESTREADOR : AUX. JUAN CARLOS RAMIREZ

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO : 10/05/17 HORA DE MUESTREO :10:20
FECHA INGRESO LAB. . 10/05/17 HORA INGRESO LAB. :12:05
FECHA DE ENSAYO. : 10/05/17 HORA DE ENSAYO . :15:30
FECHA CONTROL : 10/05/28 HORA CONTROL :15:00

RESULTADOS

ANALISIS FISICOQUIMICO

PARÁMETRO	METODO NORMALIZADO AWWA APHA, WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	NORMA BOLIVIANA NB 512
pH	4500-HB	ELECTROQUÍMICO	0,10	-	7,49	6,5 – 9,0
TURBIEDAD	2130 B	NEFELOMETRICO	0,10	NTU	0,15	5
CONDUCTIVIDAD	2510 B	ELECTROQUÍMICO	0,10	μS/cm	1267,50	1500

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	UNIDADES	CONCENTRACION	NORMA BOLIVIANA NB 512
SÓLIDOS TOTALES	2540 B	GRAVIMETRICO 180°C	0,001	mg/L	1002,00	
SÓLIDOS DISUELTOS	2540 C	GRAVIMETRICO 180°C	0,001	mg/L	936,00	1000
SÓLIDOS SUSPENDIDOS		CALCULO	0,001	mg/L	66,00	-
ACIDEZ	2310 B	TITULACION	0,33	$mgCaCO_3/L$	20,42	-
ALCALINIDAD	2320	TITULACION	0,17	$mgCaCO_3/L$	314,05	370,00
BICARBONATOS	2320	CALCULO	0,17	$mgCaCO_3/L$	314,05	-
CARBONATOS	2320 B	CALCULO	0,01	$mgCaCO_3/L$	0,00	-
CALCIO	2320- Ca D	TITULACION - EDTA	0.07	$mgCa^{++}/L$	144,29	200,00
CLORUROS	4500-Cl B	TITULACION	0,13	$mgCl^{-}/L$	3,00	250,00
DUREZA	2340 C	TITULACION - EDTA	0,17	$mgCaCO_3/L$	740,00	500,00
HIERRO TOTAL	3500-Fe B	A.A LLAMA	0,02	mgFe/L	0,22	0,30
MAGNESIO	3500-Mg E	CALCULO	0,10	$mgMg^{++}/L$	92,72	150,00
MANGANESO	3500-Mn B	A.A LLAMA	0,02	mgMn/L	0,02	0,10
POTASIO	3500-K D	A.A. LLAMA –EMISION	0,02	mgK^{+}/L	6,35	-
SODIO	3500-Na D	A.A. LLAMA –EMISION	0,02	$mgNa^{+}/L$	29,06	200,00
SULFATOS	$4500-SO_4$ E	TURBIDIMETRIA	0,36	$mgSO_4^{=}/L$	433,17	400,00

ANALISIS DE LOS RESULTADOS

La muestra puntual de agua analizada, presenta exceso en dureza total y sulfatos respecto a los valores establecidos en la Norma Boliviana NB 512 para agua de consumo.

Cochabamba, 28 de mayo del 2010

Lic. MSc. Rosario Montaño M.
RESPONSABLE LABORATORIOS C.A.S.A.

Lic. MCs. Ana María Romero J.
DIRECTORA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

UNIVERSIDAD MAYOR DE SAN SIMON
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL
Cochabamba - Bolivia

UNIVERSIDAD MAYOR DE SAN SIMON

FACULTAD DE CIENCIAS Y TECNOLOGIA

CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

C A S A

LABORATORIO REGIONAL DE CONTROL DE CALIDAD DE AGUAS
LABORATORIO PILOTO A NIVEL NACIONAL
REPORTE DE ENSAYO MICROBIOLOGICO MATRIZ AGUA

NUMERO DE REGISTRO:29209 -SC-21119
NUMERO DE MUESTRA:700 /10

PRESTATARIO : **FUNDACION PROCASHA**
DIRECCION - TELEFONO : **OTB CONVENTO MOLLE MOLLE**
DATOS DE LA MUESTRA:
DEPARTAMENTO : COCHABAMBA
PROVINCIA : CAPINOTA
LOCALIDAD : MUNICIPIO SIPE SIPE
TIPO DE FUENTE : POZO PERFORADO 85 m.
PUNTO DE MUESTREO : GRIFO
LUGAR DE MUESTREO : PATIO
PRESERVADA : SI
APARIENCIA : CLARA
TIPO DE ENSAYO : BASICO
MUESTREADOR : AUX. JUAN CARLOS RAMIREZ

REUNE LAS CONDICIONES DE TOMA Y PRESERVACION DE MUESTRAS

FECHA DE MUESTREO : 10/05/17 HORA DE MUESTREO :10:20
FECHA INGRESO LAB. . 10/05/17 HORA INGRESO LAB. :12:05
FECHA DE ENSAYO. : 10/05/17 HORA DE ENSAYO . :15:30
FECHA CONTROL : 10/05/21 HORA CONTROL :08:30

RESULTADOS

PARÁMETRO	METODO NORMALIZADO AWWA APHA,WEF	TECNICA	LIMITE DE DETECCION	CONCENTRACIÓN UFC/100 mL	NORMA BOLIVIANA NB 512
COLIFORMES TOTALES	9222-B	M.F.	0	0	0 x 100 ml
COLIFORMES TERMO TOLERANTES	9222-D	M.F.	0	0	0 x 100 ml

UFC = Unidad formadora de Colonias
M.F. = Membrana Filtrante

ANALISIS DE RESULTADOS

La muestra puntual de agua analizada cumple con los requisitos establecidos por la NB 512 para los parámetros de coliformes totales y coliformes termotoleratnes en aguas de consumo

CONCLUSION

AGUA APTA PARA CONSUMO DESDE EL PUNTO DE VISTA BACTERIOLOGICO

RECOMENDACIÓN

Se recomienda controles periódicos

Cochabamba, 28 de mayo del 2010

Montaño

Lic. MSc. Rosario Montaño M.
RESPONSABLE LABORATORIOS C.A.S.A.

Romero

Lic. MCs. Ana María Romero J.
DIRECTORA
CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL

UNIVERSIDAD MAYOR DE SAN SIMON CENTRO DE AGUAS Y SANEAMIENTO AMBIENTAL Cochabamba - Bolivia

Appendix V

Geological study at the lot of COVIVIR (excerpt)

ENSAYO DE PENETRACION ESTANDAR SPT
ASTM D-1568-98

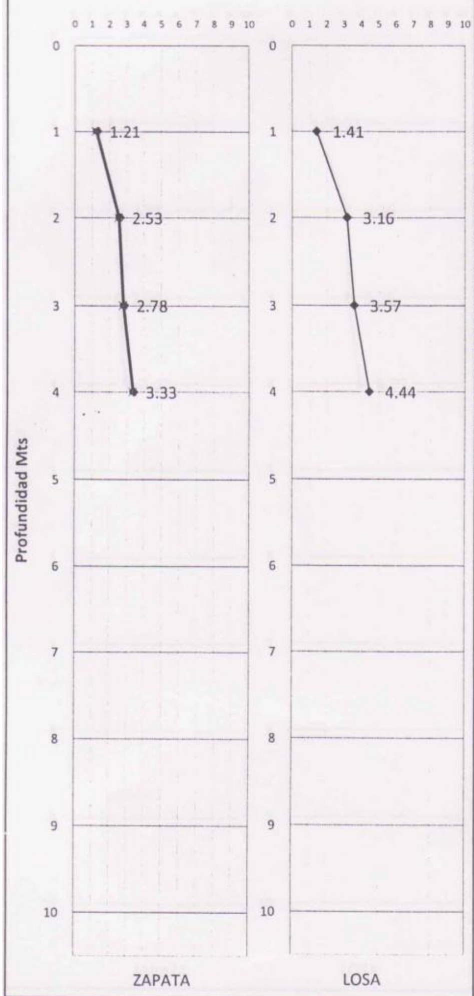
DATOS DEL ENSAYO

PROYECTO: PROYECTO DE COOPERATIVISMO DE VIVIENDA POR AYUDA MUTUA COOPERATIVA DE VIVIENDA VIRGEN DEL ROSARIO	DIRECCIÓN: CAVILOMA, MUNICIPIO DE SIPE SIPE, QUILLACOLLO

DATOS DE SONDEO

Identificacion de sondeo: SPT 001	Fecha: DICIEMBRE, 2009
Solicitante: FUNDACIÓN PROCASHA	
Coordenadas: -	Profundidad de sondeo: 4.0 m.
Alt. sobre el nivel del mar: -	Profunidad nivel freatico: No encontrado

FATIGAS KG/CM2



CLASIFICACION	Descripción	N70 SPT	PARAMETROS DE RESISTENCIA ϕ°	Cu KPa	OCR	Es kN/m2	Contenido de humedad (%)	Tamaño maximo de particulas
CL-ML	Limo arcilloso de color café amarillento	11	-	45	3.0	4425	7	NA
CL-ML	Limo arcilloso de color café amarillento	23	-	91	3.0	7170	8	NA
CL	Arcilloso de color café	23	-	91	2.3	7170	8	NA
CL	Arcilloso de color café	25	-	101	2.0	7767	9	NA

GEOTECNIA TARIFA FERNÁNDEZ SRL TELF-FAX 4240237

Juan Carlos Tarifa M. Ingeniero Civil

NA No aplicable
ND No determinado
D Muestra alterada
UD Muestra no alterada

Donde B es el ancho de zapata

ENSAYO DE PENETRACION ESTANDAR SPT
ASTM D-1568-98

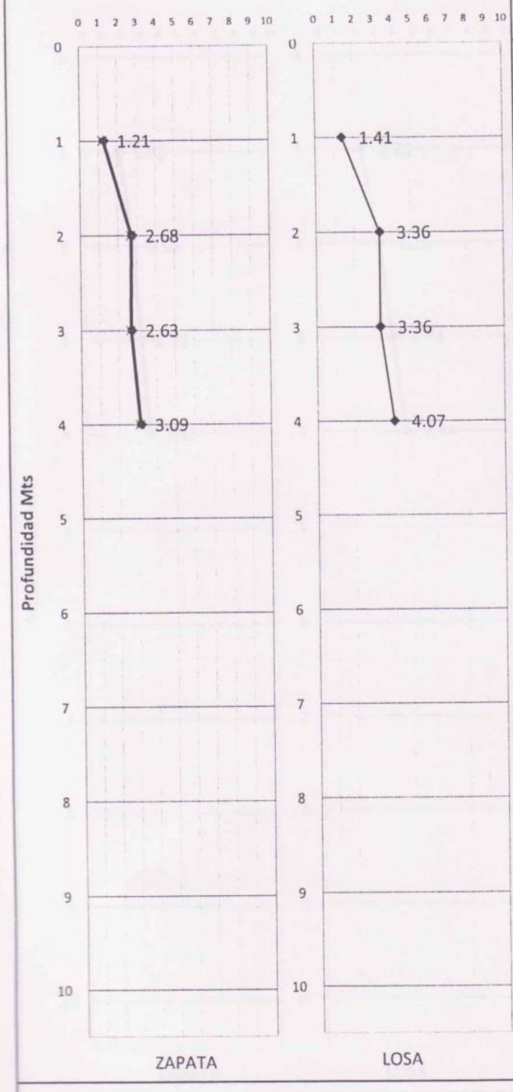
DATOS DEL ENSAYO

PROYECTO:	PROYECTO DE COOPERATIVISMO DE VIVIENDA POR AYUDA MUTUA COOPERATIVA DE VIVIENDA VIRGEN DEL ROSARIO	DIRECCIÓN:	CAVILOMA, MUNICIPIO DE SIPE SIPE, QUILLACOLLO

DATOS DE SONDEO

Identificacion de sondeo:	SPT 002	Fecha:	DICIEMBRE, 2009
Solicitante:	FUNDACIÓN PROCASHA		
Coordenadas:	-	Profundidad de sondeo:	4.0 m.
Alt. sobre el nivel del mar:	-	Profundidad nivel freatico:	No encontrado

FATIGAS KG/CM2



PERFIL ESTRATIGRAFICO	CLASIFICACION	Descripción	Nro SPT	PARAMETROS DE RESISTENCIA		OCR	Es kN/m2	Contenido de humedad (%)	Tamaño maximo de particulas
				ϕ °	Cu KPa				
	CL-ML	Limo arcilloso de color café amarillento	11	-	45	3.0	4425	8	NA
	CL-ML	Limo arcilloso de color café amarillento	24	-	97	3.2	7528	9	NA
	CL-ML	Limo arcilloso de color café amarillento	21	-	85	2.2	6812	10	NA
	CL	Arcilloso de color café	23	-	91	1.9	7170	10	NA

—◆— B = 1 Mt. —■— B = 2 Mts.
—●— B = 3 Mts. —✕— B = 4 Mts.
—— B = 5 Mts.

GEOTECNIA TARIFA FERNÁNDEZ SRL TELF-FAX 4240237

Juan Carlos Tarifa M. Ingeniero Civil RNI 3.445

NA	No aplicable
ND	No determinado
D	Muestra alterada
UD	Muestra no alterada

Donde B es el ancho de zapata

ENSAYO DE PENETRACION ESTANDAR SPT
ASTM D-1568-98

DATOS DEL ENSAYO

PROYECTO: PROYECTO DE COOPERATIVISMO DE VIVIENDA POR AYUDA MUTUA COOPERATIVA DE VIVIENDA VIRGEN DEL ROSARIO

DIRECCIÓN: CAVILOMA, MUNICIPIO DE SIPE SIPE, QUILLACOLLO

DATOS DE SONDEO

Identificacion de sondeo: SPT 003

Fecha: DICIEMBRE, 2009

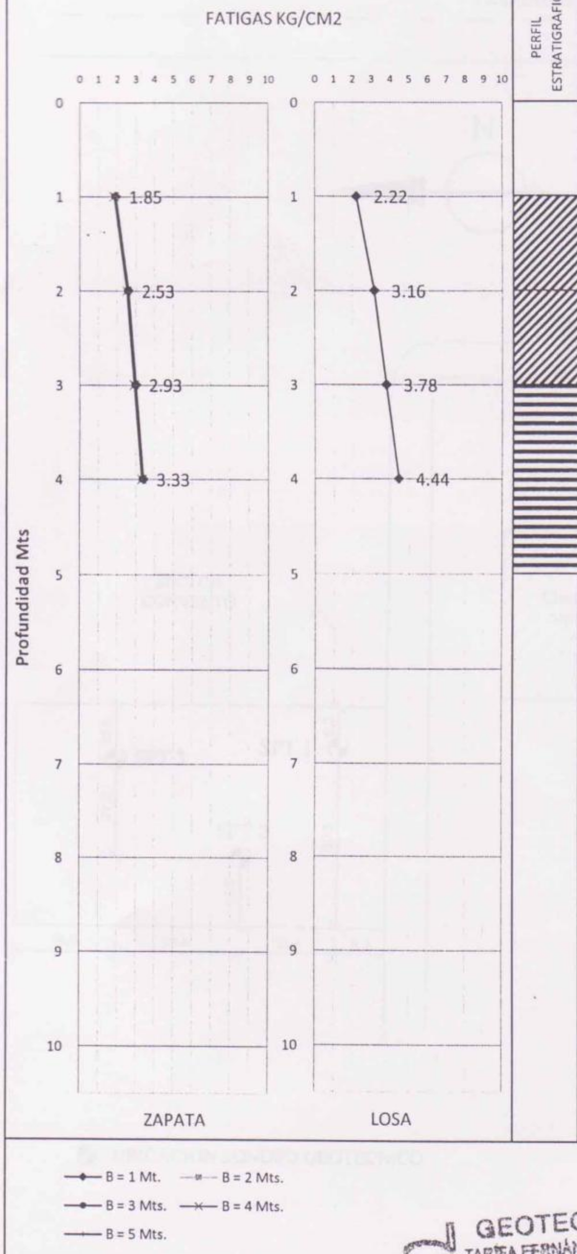
Solicitante: FUNDACIÓN PROCASHA

Coordenadas: -

Profundidad de sondeo: 4.0 m.

Alt. sobre el nivel del mar: -

Profunidad nivel freatico: No encontrado



CLASIFICACION	Descripción	N70 SPT	φ °	Cu KPa	OCR	Es kN/m2	Contenido de humedad (%)	Tamaño maximo de particulas
CL-ML	Limo arcilloso de color café amarillento	18	-	71	4.1	5977	8	NA
CL-ML	Limo arcilloso de color café amarillento	23	-	91	3.0	7170	9	NA
CL	Arcilla de color café	24	-	97	2.4	7528	10	NA
CL	Arcilla de color café	25	-	101	2.0	7767	10	NA

Donde B es el ancho de zapata

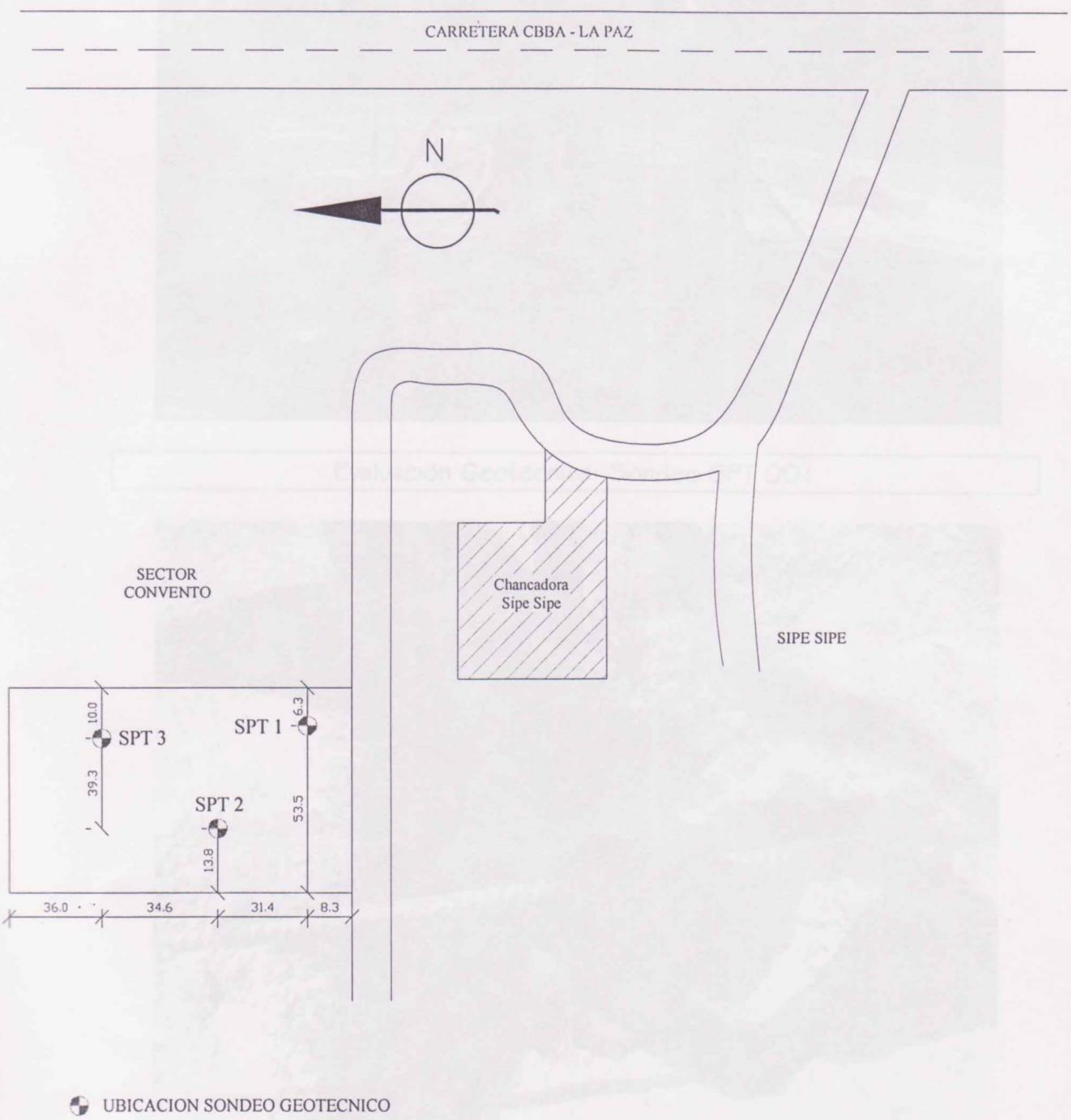
GEOTECNIA TARIFA FERNÁNDEZ SRL TELF-FAX 4240237

Juan Carlos Tarifa M. Ingeniero Civil RNI 3.445

NA No aplicable
ND No determinado
D Muestra alterada
UD Muestra no alterada

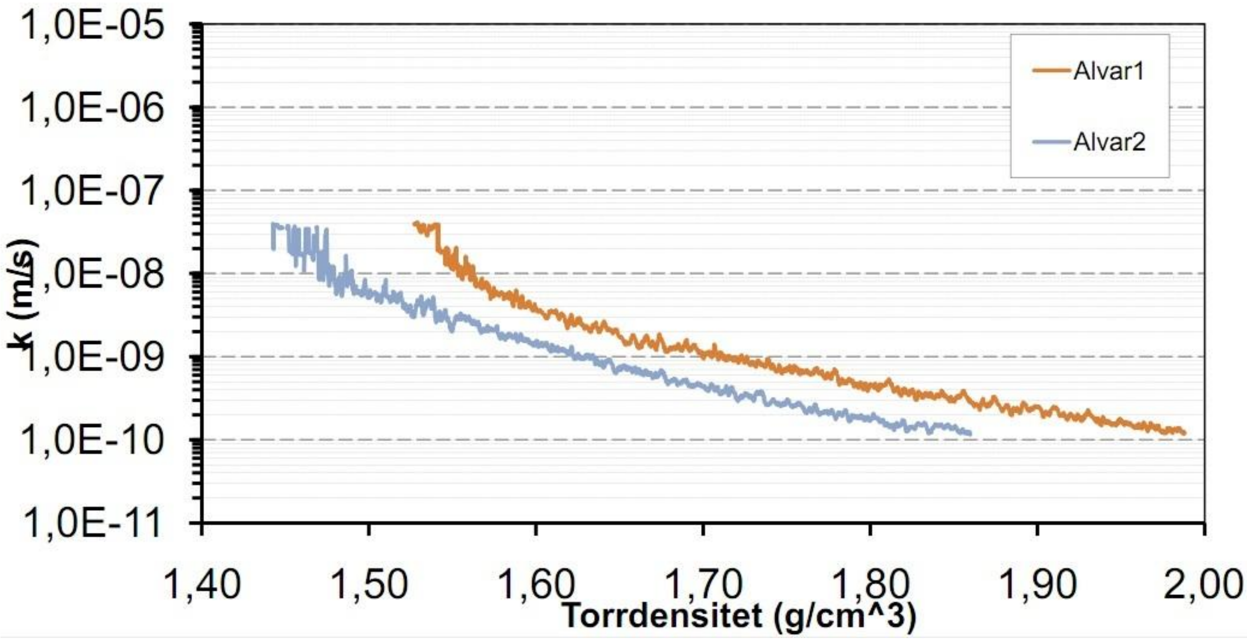
GEOTECNIA
TARIFA FERNANDEZ S.R.L.

CROQUIS UBICACIÓN DE LOS SONDEOS GEOTECNICOS
PROYECTO: URBANIZACIÓN DE VIVIENDAS VIRGEN DEL ROSARIO



Appendix VI

Test results from Chalmers University of Technology laboratory of geotechnology, for hydraulic conductivity. Two different samples, Alvar1 and Alvar2, where tested under different pressures (the X-axis). The hydraulic conductivity is shown at the Y-axis.



Appendix VII

Water qualities of Semapa's wells

DIVISION CONTROL SANITARIO

REGISTRO DE CALIDAD DE AGUA

CONTROL DE POZOS OCTUBRE - 2009 (2do. Semestre)

PUNTO DE MUESTREO	FISICO QUÍMICO													BACTERIOLOGICO	
	pH	CONDUC µS/cm	TURB NTU	COLOR UC	TEMP °C	ALCALINIDAD ml/l CO3Ca	DUREZA ml/l CO3Ca	CALCIO ml/l Ca	MAGNESIO ml/l Mg	CLORUROS mg/l Cl⁻	HIERRO mg/l Fe	MANGANESO mg/l Mn	SULFATOS mg/l SO4	Coliforme Total UFC/100 ml	Coliforme Fecal UFC/100 ml
Paso I Pozo 1	7.6	204	2	18	21	108	78	23	5	1.0	0.12	0.20	5.4	0	0
Paso I Pozo 2	7.4	136	1	14	19	68	70	22	3	1.8	0.04	0.01	11.1	0	0
Paso I Pozo 3	7.3	242	1	12	19	104	118	38	5	3.9	0.03	0.01	25.8	0	0
Paso I Pozo 5	7.3	208	1	17	20	96	82	27	3	1.6	0.12	0.01	23.4	0	0
Paso I Pozo 6	7.3	240	1	12	20	112	112	39	3	4.0	0.03	0.01	31.2	0	0
Paso I Pozo 7	7.4	189	5	5	20	72	118	28	12	1.7	0.04	0.01	27.3	0	0
Paso I Pozo 8	7.9	248	3	14	21	124	88	28	4	4.6	0.14	0.26	16.3	0	0
Paso II pozo 1	7.4	237	5	12	19	92	108	40	2	2.9	0.04	0.01	26.5	0	0
Paso II Pozo 2	7.2	258	2	12	19	108	124	34	10	3.7	0.03	0.01	33.9	0	0
Paso II Pozo 3	7.2	220	4	10	19	100	110	32	7	2.1	0.03	0.01	20.1	0	0
Paso II Pozo 4	7.2	231	3	12	19	96	104	35	4	3.4	0.04	0.01	27.4	0	0
Pozo Profundo	7.6	300	5	21	22	180	76	26	3	0.9	0.16	0.39	1.6	0	0
Caballeriza	7.2	150	3	12	21	72	76	23	4	1.9	0.01	0.00	11.5	0	0
Condores	7.3	187	1	7	19	76	88	26	6	2.9	0.01	0.00	16.6	0	0
La Granja	7.3	240	3	8	19	96	110	34	7	3.6	0.01	0.00	27.2	0	0
Vinto pozo 2	7.7	250	3	29	21	136	76	23	4	2.4	0.46	0.38	3.6	0	0
Vinto pozo 3	7.8	206	2	21	21	108	78	22	6	1.3	0.36	0.38	3.6	0	0
Vinto pozo 4	7.4	428	10	64	21	212	108	26	10	7.9	1.56	0.34	7.0	0	0
Vinto pozo 5	7.1	305	5	21	20	124	136	44	6	5.2	0.39	0.06	29.0	0	0
Vinto pozo 7	7.5	205	2	5	21	104	68	20	4	1.8	0.13	0.34	3.3	0	0
Paso III pozo 13	7.4	218	1	10	20	100	94	30	5	2.0	0.10	0.05	17.5	-	-
Paso III pozo 14	7.4	228	2	8	20	104	100	29	7	2.0	0.03	0.02	21.9	0	0
Paso III pozo 14 au	7.4	318	1	8	19	136	128	40	7	4.0	0.05	0.02	24.3	0	0
Paso III pozo 15	7.4	258	2	8	21	108	112	34	6	3.4	0.00	0.02	19.1	0	0
Pozo Santa Ana	7.0	206	5	9	21	92	102	32	5	4.5	0.03	0.01	5.2	0	0
Pozo Colquiri Norte	7.2	171	3	15	22	72	80	26	4	4.0	0.18	0.01	8.1	0	0
Pozo Colquiri Sud	7.3	141	3	16	21	60	74	20	6	2.2	0.08	0.01	17.0	0	0

Análisis Realizado por : Tec. René Rocha Rojas
Sra. Norah Mejia
Toma de Muestras : Sr. Raul Zenteno

Appendix VIII

Characteristics for Semapa's wells

POZOS, ESTACIONES ELEVADORAS Y LINEAS DE IMPULSIÓN EN ACTUAL OPERACIÓN

Ing. NMMR

N°	Nombre del Pozo	Año de perforación	Diámetro pulg.	Profund. m.	Caudal inicial l/seg.	Caudal actual l/seg.	Capacidad equipo HP	Ultimo cambio del equipo * año	Estado actual del equipo	Tiene repuesto operable	Requiere cambio de flujometro	Requiere cambio de manómetro	Ultima limpieza del pozo año	Requiere limpieza el pozo	Observaciones
POZOS VINTO															
1	V2	1978	10	130	15	10	40	1997	Regular	**No**	**Si 8"**	**Si**	2002	No	
2	V3	1978	10	131	21	14	40	1997	Regular	**No**	**Si 8"**	No	sin limpieza	Si	Colum 4", 5.3 kg/cm2
3	V4	1978	10	175	31	34	40	1997	Regular	**No**	**Si 8"**	No	sin limpieza	Si	Colum. 6", 5.1 kg/cm2
4	V5	1978	10	105	21	15	40	1997	Regular	**No**	**Si 8"**	No	sin limpieza	Si	Colum. 6", 5.5 kg/cm2
5	V7	1978	10	128,7	20	14	40	1997	Regular	**No**	**Si 8"**	**Si**	sin limpieza	Si	Colum. 4", 5.2 kg/cm2
POZOS PASO I															
6	P1	1977	10	109,2	14	10	15	1992	Regular	**No**	**Si 6"**	**Si**	sin limpieza	Si	
7	P2	1977	10 y 8	97	16	15	30	1990	Regular	**No**	**Si 6"**	**Si**	2003	No	
8	P3	1977	10 y 6	115	30	11	20	1993	Regular	**No**	**Si 6"**	**Si**	2003	No	Colum. 3" 846990 m3
9	P4	1977	10 y 8	110	40	20	40	1990	Regular	**No**	**Si 6"**	**Si**	2003	No	
10	P5	1990	10 y 8	108	22	8	10	1995	Regular	**No**	**Si 6"**	**Si**	2003	No	
11	P6	1989	10 y 8	121	50	32	50	1997	Regular	**No**	**Si 6"**	**Si**	2003	No	193505 m3
12	P7	1989	10 y 8	117,5	50	25	40	1996	Regular	**No**	**Si 6"**	**Si**	2003	No	227522 m3
13	P8	1997	6	93,7	6	3,9	10	1997	Regular	**No**	No 75 mm	No	sin limpieza	Si	0.5 kg/cm2
POZOS PASO II															
14	P1	1992	11,75	157	31	28	60	1995	Regular	**No**	No	**Si**	sin limpieza	Si	Medidor Electro. 6" sin manom.
15	P2	1993	11,75	148,31	30	29	60	1995	Regular	**No**	No	**Si**	sin limpieza	Si	Medidor Electro. 6" sin manom.
16	P3	1993	11,75	133,5	17,2	24	50	1995	Regular	**No**	No	**Si**	2003	No	Medidor Electro. 6" sin manom.
17	P4	1993	11,75	146	21	24	60	1995	Regular	**No**	No	**Si**	sin limpieza	Si	Medidor Electro. 6" sin manom.
18	PP JICA	1999	18 y 10.75	276	12	10	20	1999	Bueno	**No**	No	**Si**	2003	No	Med. diferencial 1/2" sin manom
19	PP1	1995	16	409,96	50	25	60	1995	Regular	**No**	No	No	sin limpieza	Si	Med. Electro. 1.8 kg/cm2
20	CONDORES	1998	10 y 8	159	28	24	40	1998	Regular	**No**	No necesita	**Si**	sin limpieza	Si	Sin salida para manometro
21	CABALLERIZAS	1998	11 y 8	132	26	20	30	1998	Regular	**No**	**Si 6"**	**Si**	2003	No	Sin salida para manometro

* Cambio de equipo nuevo

N°	Nombre del Pozo	Año de perforación	Diámetro pulg.	Profund. m.	Caudal inicial l/seg.	Caudal actual l/seg.	Capacidad equipo HP	Ultimo cambio del equipo * año	Estado actual del equipo	Tiene repuesto operable	Requiere cambio de flujometro	Requiere cambio de manómetro	Ultima limpieza del pozo año	Requiere limpieza el pozo	Observaciones
POZOS PASO III															
22	S13	1999	18 y 10.75	234,5	41	45	70	2001	Bueno	**No**	No	No	sin limpieza	No	Medidor electromagnético
23	S14	1999	18 y 10.75	259	45	34	70	2001	**Malo**	**No**	No	No	sin limpieza	No	Medidor electromagnético
24	S14 AUX.	1998	12 y 10	131	22	20	40	2001	Bueno	**No**	No	No	sin limpieza	No	Medidor electromagnético
25	S15	1999	18 y 10	224	45	42	85	2001	Bueno	**No**	No	No	sin limpieza	No	Medidor electromagnético
26	GRANJA	1999	12 y 8	206	45	33	85	2001	Bueno	**No**	No	No	sin limpieza	No	Medidor electromagnético
POZOS CERCADO															
27	COLQUIRI	1993	8	95	6,5	5,9		2008	Bueno	**No**			sin limpieza	Si	
28	CONDEBAMBA 1	1993	8	83,7	6,5	6			Regular	**No**	-	-	sin limpieza	No	Fuera de funcionamiento
29	CONDEBAMBA 2	2005	6	97	20	0	10	2006	Bueno	**No**	-	-	sin limpieza	No	
30	SANTA ANA	1986	6	100,7	3	2,3			Regular	**No**	Si	Si	sin limpieza	No	

* Cambio de equipo nuevo