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Designing sustainable wastewater management
A case study at the research farm Ceasip in Bolivia

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ABSTRACT

Designing Sustainable Wastewater Management
A case study at the research farm Ceasip in Bolivia

Tara Roxendal

Sustainable sanitation and wastewater management are of increasing importance around the world while certain resources are becoming scarcer and therefore more valuable. The lack of proper wastewater management causes problems and the degradation of some resources. Increasing urbanization in peri-urban areas puts extra stress on the need for finding and implementing sustainable solutions to prevent ground- and surface water contamination.

The study aimed to design a more sustainable wastewater management at the farm Ceasip located in the peri-urban area of Santa Cruz de la Sierra, Bolivia. Due to the lack of proper wastewater management on the farm, Ceasip was a likely contributor to the contamination of the groundwater. Of the farm's different wastewater sources, this study focused on the domestic wastewater and its possible reuse in agriculture. The prioritized sustainability criteria were to prevent groundwater contamination, reduce water usage and recycle nutrients.

First various wastewater management options were identified. Next these were evaluated according to the different sustainability criteria previously mentioned. In order to determine a management option, data and information were collected and processed regarding water flows, water quality, physical conditions as well as sustainability criteria within environment, technology, socio-culture, health and economy.

Results of the present conditions for Ceasip showed various characteristics, like small water flows, high nitrogen and fecal coliform concentration and clayey soils, from which suitability of different treatments was determined. Urine separation was deemed appropriate for Ceasip to increase the recycling of nutrients as well as reduce the nitrogen levels in wastewater. Treatment ponds and leach fields were designed as two wastewater treatment alternatives. For Ceasip to implement and manage water and wastewater sustainably through one of the mentioned alternatives could have a positive impact for the farm and environment, as well as serve as an example to employees, visitors and other establishments.

Keyword: sustainable sanitation, wastewater management, peri-urban farm, decentralized wastewater treatment, domestic wastewater, urine separation, groundwater contamination

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RESUMEN

Manejo sostenible de aguas residuales

Un estudio realizado en el Centro de Ecología Aplicada Simón I. Patiño en Bolivia

Tara Roxendal

El saneamiento y gestión sostenible de las aguas residuales es de creciente importancia en los tiempos modernos. Los recursos naturales son cada vez más escasos y valiosos. Mas aún, la falta del manejo adecuado de aguas residuales es causa importante de la degradación de los recursos restantes. La creciente urbanización en las zonas periurbanas acentúa la necesidad de encontrar e implementar soluciones sostenibles en el manejo de aguas residuales. En estas zonas dicho manejo (colección y tratamiento de aguas residuales) es deficiente. Como consecuencia se percibe una contaminación continua de las aguas subterráneas en estas condiciones.

El objetivo del estudio realizado fue diseñar un sistema de gestión de aguas residuales más sostenible para la granja Ceasip ubicada en la zona periurbana de Santa Cruz de la Sierra, Bolivia. El estudio se enfoca principalmente en el manejo de las aguas residuales domésticas y su posible reutilización en la agricultura. Sin embargo, cabe mencionar que las aguas residuales en la granja Ceasip provienen también de otras actividades. Para el concepto de sostenibilidad de este proyecto, son prioritarios los criterios de prevención de la contaminación del agua subterránea, la reducción del consumo de agua y el reciclaje de nutrientes.

La metodología de estudio consistió en varias etapas. Después de una extensa revisión de la literatura existente diferentes opciones de gestión fueron evaluadas de acuerdo con los criterios de sostenibilidad antes mencionados. Para hacer una elección de un tratamiento adecuado, se realizaron compilaciones y procesamiento de datos con respecto a los flujos y la calidad de aguas, las condiciones geomorfológicas, climáticas así como la evaluación de algunos parámetros ambientales, sociales, técnicos, económicos, y de salubridad.

En las condiciones actuales, los resultados de las evaluaciones de la granja, resaltaron aspectos críticos sobre los que se propusieron algunos tratamientos alternativos; por ejemplo el aumento en el reciclaje de nutrientes así como la reducción de los niveles de nitrógeno en las aguas residuales. La separación de la orina se consideró de gran importancia para la gestión apropiada de las aguas residuales de Ceasip. Al final se sugirieron dos posibles alternativas para el diseño del tratamiento de aguas, la utilización de lagunas o de lechos filtrantes con arena, cuya contribuiría positivamente tanto como para el entorno local y el personal de la granja así como para la comunidad en general, sirviendo como ejemplo para otros establecimientos.

Palabras claves: saneamiento sostenible, gestión de aguas residuales, periurbana, tratamiento en pequeña escala, aguas residuales domésticas, separación de orina, contaminación de las aguas subterráneas

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REFERAT

Hållbar avloppsvattenhantering på demonstrationslantbruket Ceasip i Bolivia

Tara Roxendal

Hållbar sanitet och avloppsvattenhantering är av ökande vikt runt om i världen. Resurser blir allt knappare och mer värdefulla medan bristen på hållbar hantering även skapar problem och degradering av återstående resurser. På grund av den ökande urbaniseringen är grundvattnet i städernas periferier speciellt utsatt eftersom avloppsvattenhantering saknas där.

Syftet med denna studie är att designa en mer hållbar avloppsvattenhantering för gården Ceasip i peri-urbana Santa Cruz de la Sierra, Bolivia. I nuläget saknas en lämplig lösning på gården. Av de olika typerna av avloppsvatten på gården, fokuserar denna studie främst på avloppsvattnet från hushåll och möjligheterna att återanvända det inom jordbruket. För hållbarhetskonceptet i uppsatsen, prioriteras följande kriterier: skydd av grundvattnet, minskning av grundvattenkonsumtion och näringsåtervinning.

En litteraturstudie gjordes över olika avloppsvattenhanteringsalternativ som sedan utvärderades enligt hållbarhetskriterierna. För att bestämma det mest lämpliga hanteringsalternativet, samlades data och information om vattenflöden, vattenkvalitéer, klimat, geomorfologi och även för miljö, teknik, hälsa, ekonomi och kultur.

Resultaten från sammanställningen visade på olika egenskaper från vilka lämplig hantering bestämdes. För att öka återvinningen av näringsämnen och minska kvävekoncentrationerna i avloppsvattnet, visade det sig vara lämpligt att använda urinsortering. Två behandlingsalternativ designades, och det föreslogs antingen behandlingsdammar eller förstärkta infiltrationsanläggningar. Då någon av dessa alternativ tillämpas på Ceasip skulle man även kunna påverka lokalt och regionalt genom att sätta ett bra exempel.

Nyckelord: hållbar sanitet, avloppsvattenhantering, peri-urban gård, småskaliga avloppsvattensystem, hushållsavloppsvatten, urinsortering.

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PREFACE

This thesis was realized as the ending project of 30 ETCS for the Master of Science program in Aquatic and Environmental Engineering at Uppsala University, Sweden. The fieldwork was carried out at the Center for Applied Ecology run by the Foundation Simon I. Patiño (Ceasip) as a Minor Field Study (MFS) financed by the Swedish International Development Agency (Sida). Other financial supporters that made the project possible were ÅF and Miljöfonden. The subject reviewer was Håkan Jönsson, professor at the Department of Energy and Technology, Swedish University of Agricultural Sciences. The supervisor in Bolivia was Christian Bomblat, director of Ceasip.

I would like to give special thanks to my supervisor Lars Hylander for his tips and reliable support, to Christian Bomblat for receiving me at the Ceasip farm, for giving me the opportunity to do this project and for his assistance and input, and to Håkan Jönsson and Sahar Dalahmeh for their technical input and support. My gratitude also reaches out to all the employees at Ceasip who helped me with so many practical aspects of the project and for making me feel comfortable at the farm, especially Toño Morales, Chenty Ruíz, Marco Garrido, and Regis Viveros. I would also like to thank the Bolivian families who took me in like a daughter and showed me the heart of Bolivian culture. I thank also the team of Naturaleza Extrema for revealing some of Bolivia's purest natural treasures to me and for practical support with the project. Thank you to all the people who have received me during field trips related to the project and the employees at Laboratório Procesos Químicos and UTALAB for putting up with my curious presence and probing questions and observations. I would also like to express my gratitude to the Department of Building and Environmental Engineering at the Lund University and Lennart Qvarnström for permission to use figures and photos in this thesis. Finally I would like to thank my dear friends who have helped motivate me and on whom I have leaned upon for support.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

I Santa Cruz, Bolivia, som på många andra håll runt om på jorden, pågår allvarlig förorening av grund- och ytvatten till följd av bland annat dålig sanitet och avloppsvattenhantering. Medan innerstaden i Santa Cruz har fungerande avloppssystem, sträcker sig inte detta nät långt. Speciellt i utkanterna av staden är reningen av avloppsvattnet från de flesta hemmen otillräcklig och hanteringen dålig. Ofta handlar det om att avloppsvattnet leds ner i hål i marken utan rening eller slängs ut på gatorna för att rinna vidare till floder. Föroreningar sträcker sig ner till 100 meters djup på vissa platser under staden. Detta innebär att grundvattnet som är stadens enda dricksvattenkälla blir odugligt som dricksvatten. Lyckligtvis kommer stadens huvudvattenförsörjning från ett djup på ner till 350 meter, men föroreningarna sprider sig, och många bostäder har egna brunnar som inte alls är särskild djupa. Dessutom är grundvattenförbrukningen i staden ohållbar, då det redan inom 10-15 år kan komma att bli större efterfrågan på grundvattnet än vad som hinner återbildas på naturlig väg. Santa Cruz är en av världens snabbast växande städer vilket innebär att problematiken kommer att förvärras både vad gäller förorening och efterfrågan på dricksvatten om inte åtgärder görs omgående.

I denna studie togs ett par olika lösningar fram för att förbättra det småskaliga avloppsvattensystemet för lantbruksgården Ceasip som ligger 20 km från Santa Cruz centrum. Fastigheten är hotad av både ökenbildning och urbanisering. Syftet med studien var att tillämpa en avloppsvattenhantering som skulle förhindra grundvattenförorening och dessutom skapa vatten- och näringskretslopp för att främja en hållbar utveckling. Att skapa kretslopp av näringsämnen som fosfor och kväve, är speciellt viktigt på en global skala eftersom fosfor är en ändlig resurs och framställningen av kvävegödsel är en extremt energikrävande process.

Kvalitén på och flödena av grund- och avloppsvatten på Ceasip studerades i fält. Ceasip är ett demonstrationslantbruk där nötkreatur föds upp och ett antal olika grödor odlas. Mjölk produceras och tas om hand på ett eget litet mejeri. Det visade sig att den största grundvattenförbrukningen skedde i frukt- och grönsakslandet medan de största årliga kväveflödena fanns i avloppsvattnet från mejerifabriken samt i hushållsavloppsvattnet. Det var förhållandevis små årliga kväveflöden i avloppsvattnet från ladugården.

Urinsortering med hjälp av speciella toaletter och urinoarer var en del av lösningen som föreslogs. Eftersom urin är en stor källa till växttillgängliga näringsämnen, speciellt kväve, skulle det vara lätt att återföra dessa till kretsloppet som gödselmedel då det fanns många behövande grödor på gården. Dessutom var jorden mycket näringsfattig. Urinsortering skulle även underlätta behandlingen av det övriga avloppsvattnet.

För att välja mellan lämpliga avloppsvattenhanteringsalternativ, gällde det att pussla ihop verkligheten med teorin. Utifrån en omfattande litteraturstudie samt en mängd data från platsen, evaluerades och jämfördes de olika systemalternativen. För att sluta vatten- och näringskretsloppet, föreslogs det att avloppsvattnet skulle användas till bevattning av grödor på Ceasip. För att kunna göra detta utan hälsorisker, krävdes det att man följer vissa normer som har fastställts av Världshälsoorganisationen. För att uppfylla dessa är det bland annat viktigt att minska riskerna för människor att komma i kontakt med sjukdomsalstrande smittoämnen, patogener, som kan finnas i avloppsvatten. Ett bra alternativ för att döda patogener är så kallade behandlingsdammar. Detta är ett enkelt och effektivt behandlingsalternativ samtidigt som vattnet blir lättillgängligt för bevattning av grödor. Dock behövs fortsatta studier för att avgöra om det skulle bidra till ökat antal insekter. Fortsatta studier behövs även för att titta på den ekonomiska och produktiva lönsamheten för sådana små flöden som gården har.

En annan lösning till behandlingsdammarna togs fram för att gården skulle ha andra alternativ att välja mellan. I det här fallet blev det så kallade infiltrationsbäddar. Då renas avloppsvattnet naturligt medan det sakta infiltreras ner i marken, men det skulle innebära att varken näringen eller vattnet nyttjas produktivt.

Ceasip har ett 20-tal anställda samt mottagning av besökare. Detta innebär att de har stor potential att kunna sprida kunskaperna vidare. Framgång med hanteringen av grund- och avloppsvatten på ett mer hållbart sätt på Ceasip skulle därför kunna påverka lantbruket och miljön både lokalt och regionalt. Båda de föreslagna avloppsvatten-hanteringsalternativen skyddar grundvattnet och med hjälp av urinsortering skulle man på enkelt sätt kunna återföra näring till kretsloppet. Med förbättrad avloppsvattenhantering skulle man därför kunna spara närings-, grundvatten- och energiresurser, samtidigt som människors hälsa och natur skyddas.

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DEFINITIONS AND ABBREVIATIONS

As: Arsenic

BOD: Biological oxygen demand. A measurement of biologically degradable organic matter.

Bs: Bolivianos. Bolivia's currency.

Ceasip: Centro de Ecología Aplicada Simón I. Patiño

Cd: Cadmium

CH_4: Methane

CO_2: Carbon dioxide

COD: Chemical oxygen demand. A measurement of chemically degradable organic matter.

Cu: Copper

DALYs: Disability adjusted life years. Population metric of life years lost to disease due to both morbidity and mortality. (WHO, 2006)

FAO: Food and Agriculture Organization of the United Nations

FC: Fecal Coliform bacteria

Fe: Iron

g: gram

Hg: Mercury

HRT: Hydraulic retention time

K: Potassium

K: Hydraulic conductivity/soil permeability

l: liter

m: meter

MPN: Most probable number. A unit used to measure the number of bacteria in a sample.

N: Nitrogen

NH_4^+: Ammonium

NGO: Non-governmental organization

$N0_3^-$: Nitrate

p: person

P: Phosphorus

Pb: Lead

TSS: Total suspended solids

TDS: Total dissolved solids

Peri-urban: Around/about an urban area

S: Sulfur

Senamhi: Bolivia's national meteorological and hydrological service

WHO: World Health Organization

Zn: Zink

1. INTRODUCTION

1.1. BACKGROUND

The need for sustainable water management and sanitation is a matter of increasing importance in the world. Maintaining good water supply and sanitation is crucial for keeping the population in good health. The UN states that access to safe drinking water and sanitation is a human right. However, 884 million people in the world lack access to improved drinking water while 2.6 billion people lack improved sanitation. (WHO/UNICEF, 2010) In the year 2008, the UN set the goal to halve the proportion of the population who lack sanitation by the year 2015, but this goal seems far from being achieved (WHO/UNICEF, 2010). Furthermore, a majority of the current systems of sanitation in the world are threatening these human rights for future generations because of the environmental contamination that they cause and their lack of sustainability. This study focuses on people who currently have access to decent sanitation, but whose system of sanitation is not sustainable in the long run and poses threats to the environment; thereby threatening the health of those people who depend on that environment.

Global food security depends upon the availability of water, nutrients and energy which in turn currently depends on non-sustainable practices and non-renewable resources. Water is a resource that is becoming increasingly scarce in many parts of the world, especially in developing countries. Techniques to reuse and recycle resources should be implemented to achieve sustainable food production and long-term food security, such as the recycling of the nutrients in wastewater for food production. Wastewater is simply too valuable to waste and irrigation with wastewater results in higher crop yields than with freshwater (Mara, 2004).

Bolivia is a landlocked country nestled in the heart of South America (Figure 1). Between the Andes Mountains to the west and the tropical region to the east and lowlands in the south, it possesses some of the world's most varying and extreme natural landscapes that are certainly worth protecting (CIA, 2011). Due to the high negative impacts of unimproved sanitation, sustainable development of water and sanitation systems in Bolivia is urgent. Until proper solutions to treat wastewater are implemented, environmental problems such as contamination of groundwater, surface water, earth and air, as well as eutrophication persist. Other current environmental sustainability problems that Bolivia faces include deforestation caused by slash and burn agriculture and international demand for tropical timber as well as biodiversity loss, desertification and soil erosion (Nations Encyclopedia, 2010). Water supplies used for drinking and irrigation are also being polluted by industry, among other causes (CIA, 2011).

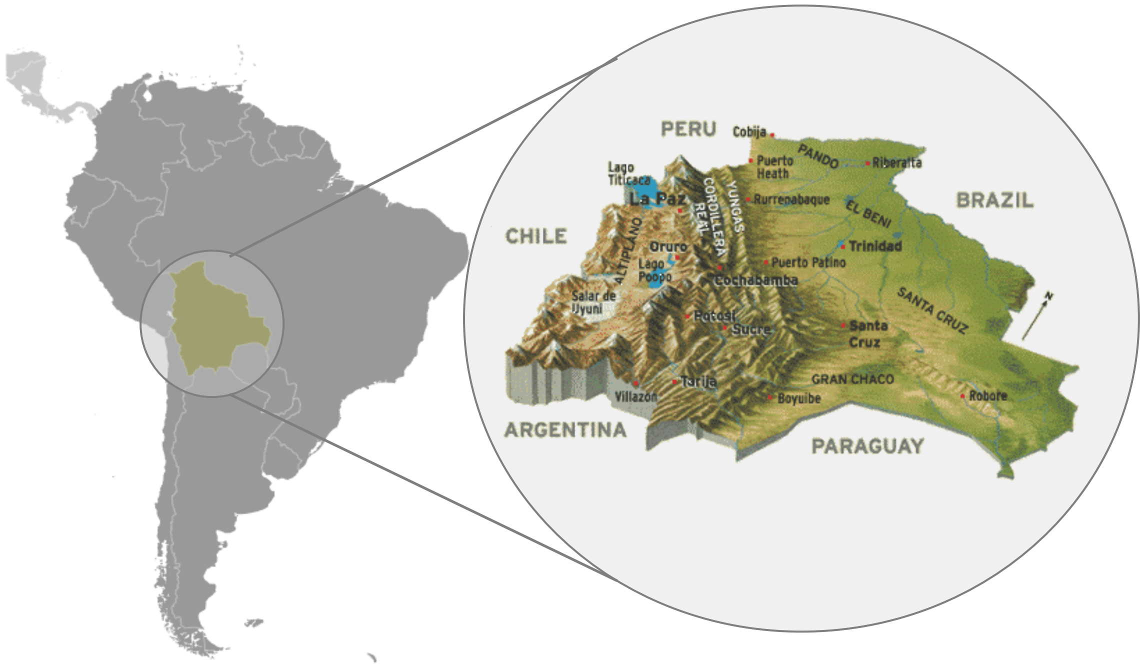

Figure 1. Left: Bolivia´s location in South America (adapted from CIA, 2011). Right: Bolivia's varying landscapes (adapted from www.boliviabella.com, 2011).

The rapidly increasing population and urbanization puts high pressure on the water and sanitation issue. The city of Santa Cruz, Bolivia, has a population of over 2 million including surrounding rural areas and a high annual growth rate of 4.29% (INE, 2001) making it one of the fastest growing cities in the world (City Mayors Statistics, 2011). The main water and sanitation challenge lies in providing services to rapidly growing cities, especially to the peri-urban areas. In the year 2008, only 25% of the total Bolivian population had access to improved sanitation while 86% of the total population had access to improved drinking water. A significantly higher percentage had improved water and sanitation in urban areas. (WHO/UNICEF, 2008) Many NGOs and organizations have realized water and sanitation projects in Bolivia. See the Appendix 1 for a few examples of related sanitation projects.

The Bolivian farm where this water and wastewater study was conducted is known as the Centro de Ecología Aplicada Simón I. Patiño [(Ceasip) or Center for Applied Ecology Simon I. Patiño]. The Ceasip is an ecological research farm, founded and funded by the Foundation Simon I. Patiño, a Swiss-based foundation. The foundation works toward the health and well-being of the Bolivian population. Within his framework, the Ceasip supports activities that encourage the Bolivians to get to know, appreciate and protect their natural resources. Ceasip's main activities currently include development of a model of an economically and ecologically sustainable farm in an area threatened by desertification.

Since 2007, the farm has been undergoing a complete reengineering process. During this process it became evident that no proper management of water and wastewater exists. As the Ceasip is planning an expansion of its operations, a master plan was developed 2008-2009 to double livestock production and to improve reception of visitors among other objectives. If implemented correctly, the Ceasip's sustainable water and wastewater management system could have considerable local, regional and national impact.

1.2. OBJECTIVE

The objective of this project was to select and design an onsite sustainable wastewater management system for the research farm Ceasip, located in the Bolivian tropics outside of the city of Santa Cruz de la Sierra. Future expansions of activities of the farm and new buildings were considered for the design. Water and wastewater management on the farm is discussed as a whole although a specific wastewater treatment is limited to the eastern buildings, which currently include three households, the office and the cafeteria. Possible reuse of wastewater in agriculture is also discussed.

1.2.1. Specific objectives

- Assess the current situation:
  - Quantify water usage, water losses and production of wastewater from the farm households and activities.
  - Determine the quality of wastewater for relevant parameters.
  - Determine current physical condition (i.e. slopes, soils, etc.)
- Compare wastewater management solutions and decide upon the most appropriate solution considering sustainability criteria in the following aspects: environmental impact, health, economy, technical function, and socio-cultural attitudes.
- Design a suitable wastewater management system according to conditions by choosing placement, dimensions, slopes and materials, and summarize critical points in technical sketches.

1.3. GENERAL LIMITATIONS

The time dedicated to fieldwork of the study was limited to three months, April through June 2011. The data collected during this time period was not representative of the whole year, especially considering the change in seasons, so this was taken into consideration.

Although future expansions of the farm are considered in the solution, the specific design is not made for all the future buildings. Possible solutions are discussed for the western side of the farm, but will not be designed specifically. See the map over the current buildings where the eastern buildings are circled in red (Figure 2).

Figure 2. Map of current buildings at Ceasip farm with the "Eastern Buildings" circled in red (modified from Ceasip, 2008).

Management of water and wastewater of the dairy factory on the farm was studied by another student, so most of the detailed quantity and quality investigation is left out of this thesis.

The study was limited to analyze only the parameters of the present conditions of highest relevance in determining the improved wastewater system. Some wastewater parameters mentioned in the legislation were not studied because they were considered of little importance in fulfilling the objective. Specific limitations are discussed under *2.2.2. Parameters*.

Precise water balance calculations, stormwater and anal cleansing water were excluded from the study due to time and resource limitations. Although cleansing water for anal washing does occur to some extent in Bolivia, it is not assumed to be important in this study since toilet paper use was more common in the studied area.

The prioritized sustainability criteria were those regarding sustainability problems of special relevance in Bolivia, namely potential water scarcity, groundwater contamination and recycling of plant nutrients. Some specific limitations of the sustainability criteria are mentioned under *3.1.4. Investigation of sustainability criteria in present conditions*.

1.4. LAYOUT

The layout of this thesis is motivated as follows:

Literature studies were done and are summarized in two different sections of the thesis: *Theory* and *Review of relevant technology*. They are focused on providing the basics relevant to wastewater management and summarizing suitable wastewater management alternatives. *Site description* gives some background information to understand the context of the study and some justification and relevance of the study, as well as providing some of the information that is necessary for designing and dimensioning wastewater management. *Methods* describes the way in which the data was collected and compiled as well as some calculations of relevance. The results of this thesis are divided into three different sections. The most important data results from the field study are summarized and discussed in *Present conditions results and discussion*. Next, the evaluation and selection of management and technology options is presented in *Selection of technologies and management approach*. Two alternative systems for wastewater management are designed in *System design* based on the previous sections. Finally, the *Discussion* and *Conclusions* are given to discuss and summarize results and to give recommendations for the water and wastewater management in different sectors of the farm.

2. THEORY

Theoretical studies included defining sustainability and water and wastewater quality in the context of this thesis.

2.1. SUSTAINABILITY

2.1.1. Defining sustainability

Sustainability is a broad term; according to the dictionary (Dictionary.com) it is the ability to be sustained, supported, upheld, or confirmed. An *environmental science* definition of sustainability is the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance. Sustainability is now a term used in a popular sense when referring to human sustainability on planet Earth. A widely used quoted definition of sustainability and *sustainable development* originating from the Brundtland Commission of the United Nations (1987) is the following: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Sustainable development is often depicted with consideration to the three sustainability pillars, environment, society and economy. The classic illustration, as seen in Figure 3 to the left shows that sustainable development must take equal consideration to environmental, social and economic aspects. In Figure 3 in the right hand side however, another version preferred by many ecologists and environmentalists is depicted. It shows that the three pillars are not equal and should not be considered equally for sustainability. Rather, in order for development to be sustainable, economy and society both rely on the environment, and must therefore be contained within its limits. The economy in turn, relies on society (and is a part of society), which is why it must be contained within the limits of society.

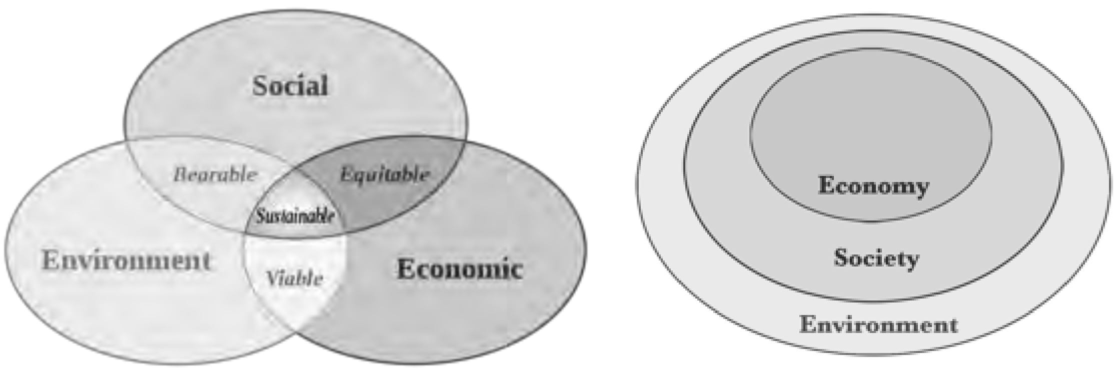

Figure 3. Left: The three pillars of sustainability, Right: Alternative depiction of three pillars of sustainability (adapted from Wikimedia commons, 2011).

In this study, the sustainability criteria will now be defined, based partly on the three pillars, and inspired by WHO guidelines (2006) and Malmqvist et al. (2006) in the five aspects being evaluated, environment, health, socio-cultural attitudes, economy and technical function for sanitation systems.

Environment: The study considers specific conditions on farm and locally. Criteria that contribute to better environmental sustainability or detract from environmental sustainability are as follows:

- Potential reduction of water usage
- Potential use of wastewater
- Potential recycling of nutrients
- Removal of BOD from wastewater
- Removal of suspended solids from wastewater
- Removal of nutrients from wastewater
- Removal of heavy metals etc.
- Contamination of groundwater and surface water
- Eutrophication risk
- Emission of greenhouse gases
- Use of high quality energy forms (electricity, gas)
- Use of resources (materials)

Health: The study considers the health risks involved. A safer system with less risks means is more sustainable. A few general criteria are:

- Pathogen removal efficiency
- Maintenance and worker safety
- Potential consumer safety
- User friendliness and user safety

Socio-cultural: The study takes into account sustainability criteria on both household and institutional levels. A system that is not socially functional is not sustainable. Some criteria are the following:

- Acceptance and convenience
- Need for user/management education
- Bad odors
- Legal acceptability
- Appropriateness in local context

Economy: The study considers the economic advantages and disadvantages. The advantages need to outweigh the disadvantages for sustainability, although in the short run, the advantages might not be obvious. A few criteria to look at are as follows:

- Potential profit
- Investment cost (materials, labor, rental of equipment, installation)
- Maintenance and operation cost

Technical function: The study takes into account the technical challenges regarding design and materials in the sustainability criteria.

- Technical feasibility: Availability of material locally, availability of qualified construction/maintenance persons, suitable physical conditions
- Technical simplicity: lacking in need of advanced technology or technical parts
- Maintenance: Frequency and difficulty

- Durability: Material and structural

2.1.2. The importance of plant nutrients

It is important to stress the value of nutrients in the sustainability discussion. Nutrients, especially the macronutrients nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) are central for food security. They are a part of the discussion since (combined with carbon, hydrogen and oxygen) they are the building blocks of life; however, they are an item often overlooked even among educated professionals. They are a resource needed in fertilizers for crops. Nitrogen (N) and phosphorus (P) are two important macronutrients since they are the most limiting for plant production. Fertilizer N is one of the products which has allowed for population growth and it is estimated that only half of the current global population would have food security without the use of this product (Dawson & Hilton, 2011). Phosphorus is another nutrient which has made the mass-production of food possible. Approximately 85% of processed P is used as agricultural fertilizer and as a mineral source for animal nutrition (Dawson & Hilton, 2011).

Nitrogen is a resource that exists in great quantities in gas form in the atmosphere, effectively unlimited, but in order to produce the plant available fertilizer N in the forms of nitrate ($N0_3^-$) or ammonium (NH_4^+), vast quantities of energy are required. Over 90% of total energy required to produce fertilizers is accounted for in the production of fertilizer N. Year 2008 this was equivalent to 1.1% of the total global energy use. (Dawson & Hilton, 2011) Currently this process is heavily dependent on the energy from fossil fuels. Of the non-renewable resources that modern society is dependent upon, fossil fuels have been largely discussed and given much attention from a sustainability perspective. The term “Peak Oil” has been used to describe the point of maximum possible production of fossil oil, the peak of the production curve. Some researchers, including Björn Lindahl (2010) imply that such a peak will be reached already year 2012, which entails drastic consequences in terms of production and circulation of fertilizer N.

The importance of P in the sustainability criteria should also be stressed. Phosphorous is a non-renewable resource and unlike nitrogen, it does not have a gas phase. The P reserves, which are relatively limited, are mined from phosphate rock mines in a relatively few countries (biggest producers being China, Morocco and the USA). There is a predicted “Peak phosphorous,” but because of little reliable data and the complexity of making such an estimation, it is debated whether the production could dwindle in anywhere between 50 to 400 years. (Cordell, 2009; Dawson & Hilton, 2011)

2.2. CHARACTERISTICS OF WASTEWATER AND EXCRETA

The composition of wastewater varies greatly depending of the source. The wastewater produced in a household typically differs greatly from wastewater produced in industry. Because the focus of this investigation is on the treatment and reuse of household and stable wastewaters (and not industrial waters), the relevant components other than water consist mainly of urine, feces, soaps and detergents, other cleaning chemicals, food scraps and greases. In some cases toilet paper is used, but most frequently in Santa Cruz, Bolivia, toilet paper is disposed of in a garbage can. The designing of the wastewater treatment system in this thesis will however allow for toilet paper to be flushed down the toilet (See *6. Review of relevant technologies*).

Wastewater can be a great resource, but can also cause problems, especially if not properly used or treated. On the resource side, wastewater is full of the nutrients that are necessary in agriculture. Problems with wastewater include the potential existence of pathogens and hazardous substances, such as heavy metals, persistent organic pollutants, endocrine disruptors and medical residues (Malmqvist et al., 2006).

2.2.1. Risks and guidelines of wastewater reuse

Regarding the reuse of treated wastewater as irrigation water, it is important to overcome potential salinity hazards, toxicity hazards and health hazards. Full recommendations and guidelines are given by, for example, FAO (see M.B. Pescod, 1992) and WHO (see WHO, 2006). Some main points are summarized in Table 1.

Table 1. Guidelines for irrigation water. Adapted from WHO (2006)

Parameters	**Unit**	**Degree of restriction on use**		
		None	**Slight to moderate**	**Severe**
pH		6.5-8		
Salinity (Cond)	µS/cm	<700	700-3000	>3000
Total N	mg/l	<5	5-30	>30
TDS	mg/l	<450	450-2000	>2000
TSS	mg/l	<50	50-100	>100
Fe	mg/l	<0.1	0.1-1.5	>1.5
As	mg/l	0.1*		
Cd	mg/l	0.01*		
Pb	mg/l	5*		

*Maximum recommended limit

Salinity

The tolerable level of salinity for crops in irrigation water depends not only on the types of plants, but also on other factors including climate and soil types. The plant tolerance when in direct root contact with saline water, typically ranges between conductivity levels of 600 – 10 000 µS/cm. Lists of crop tolerance levels can be found for example in FAO recommendations (see Tanji, 2002). The climate can have significant influences if there is an abundance of rainfall to leach salts from soils. The soil and drainage characteristics within the root zone also influence the ease of leaching or salt accumulation. (Evans, 2006)

Toxicity

Potential toxins found in urban wastewaters include heavy metals. Irrigation with such water gives rise to elevated levels in soil and undesirable accumulations in plant tissue and can even cause crop yield reductions. Heavy metal content and other toxic chemicals should therefore be monitored periodically in the soils and crops irrigated with wastewater and compared to maximum recommended limits. (M.B. Pescod, 1992)

Health

Potential health hazards can be caused by irrigation water especially due to microbial quality, but risks can be minimized by considering crop type, irrigation type and worker protection (M.B. Pescod, 1992). The WHO guidelines include an integrated approach of combined risk assessment and risk management to control water-related diseases. Health based targets, which are defined to provide the relevant level of protection against each hazard, can be measured in the achievement of 10^{-6} DALY ("disability adjusted life year," a standard metric of disease) per person and year. Depending on the crop types etc., a $\log_{10}$ pathogen reduction of 2-7 is required to achieve this target. (WHO, 2006) Some control measures for pathogen reduction are given in Table 2.

Table 2. Pathogen reductions achievable by various health protection measures (WHO, 2006)

Control measure	Pathogen reduction (log units)	Comments
Wastewater treatment	1-6	The required pathogen reduction to be achieved by wastewater treatment depends on the combination of health treatment measures selected.
Localized (drip) irrigation (low-growing crops)	2	Root crops and crops such as lettuce that grow just above, but partially in contact with the soil
Localized (drip) irrigation (high-growing crops)	4	Crops such as tomatoes, the harvested parts of which are not in contact with the soil
Pathogen die-off	0.5-2 per day	Die-off on crop surfaces that occurs between the last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc.
Produce washing with water	1	Washing salad crops, vegetables and fruit with clean water
Produce cooking	6-7	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction

2.2.2. Parameters

The parameters of greatest interest in determining the water and wastewater quality relevant to fulfilling the objectives, and which were therefore analyzed, follow. (See Table 7 for limitation of parameters.)

Temperature and pH

The pH-value, a measurement of acidity or alkalinity, and temperature, the quantitative measurement for heat, can be useful to indicate if the wastewater is "normal," and if treatment or use/disposal methods are appropriate. Certain chemical processes and biological activity require a suitable temperature and pH. Extreme pH values and temperatures can be inhibiting to processes or to microorganisms in treatment.

Conductivity/Salinity

The electric conductivity is a measurement of a material's ability to conduct electric current. It can be measured in Siemens per meter (S/m). In a solution, ions conduct electricity. Since dissolved salts ionize the solution, conductivity can be used to indicate the salinity. Pure water will thus have a lower conductivity than impure water.[1] The salinity of water is especially interesting to determine if it is suitable for irrigation because an accumulation of salt in soils is undesirable and crops can have direct sensitivity to high salt levels.

Total suspended solids

Total suspended solids (TSS) in wastewater, is all the matter that can be settled out under the right conditions. It is an important parameter for treatment design since it determines the necessity of pretreatment. If there is a high content of suspended matter that is not removed sufficiently, there is great risk of clogging the treatment system. Also, pollutants such as metals and organic chemicals are associated with incoming suspended matter. (Kadlec & Knight, 1996, ss. 315-339)

Total dissolved solids

Total dissolved solids (TDS) are the sum of all dissolved colloidal and suspended (volatile and non-volatile) in a liquid. They can be in molecular, ionized or micro-granular form as long they are suspended. Particles that pass through a 1.2-µm filter are considered dissolved (Morel & Diener, 2006). The measurement of TDS can be a quantitative indicator of contaminants in wastewater.[2]

Biological oxygen demand (BOD)

Biological oxygen demand, or BOD, is a parameter that is useful in measuring the amount of degradable carbon compounds in the system. BOD can be measured for five days, thereby the term "BOD_5." Both *aerobic* and *anaerobic* bacteria can consume carbon compounds, breaking them down into CO_2 and CH_4. (Morel & Diener, 2006) The treatment must be designed so that the load of BOD does not exceed what can be degraded in the system.

Greases and fats

Greases and fats are an insoluble group of substances in wastewater (Morel & Diener, 2006). Molecularly, greases and fats contain more energy than protein and carbohydrates. This means that they have high persistence and a low rate of

[1] Drinking water may typically have a conductivity of 5 - 500 µS/cm.
[2] Freshwater has a TDS concentration of less than 1500 mg/l.

biodegradation. Pretreatment of wastewater should be designed to remove the majority of greases and oils so as to prevent the clogging of the system. In domestic wastewaters, greases and fats are mainly found in the kitchen wastewater.

Total nitrogen

Total N is the combination of all the organic and inorganic N forms together. Nitrogen is an important nutrient found in wastewater. Because it is generally one the most limiting nutrients in the growth of plants and algae, it is one of the key contributors in eutrophication when discharged in abundance. Nitrogen has a complex cycle including a gas phase and can be found naturally in various different forms, both organic and non-organic. (Havlin et al. , 2005)

Ammonium (NH_4^+*)*

Ammonium, an inorganic plant-available nitrogen type, can be found in high concentration in domestic wastewaters because of excreta (especially urine). NH_4^+ can be converted to $N0_2^-$ and $N0_3^-$ through nitrification, immobilized by bacteria, taken up by plants, or converted to NH_3 and volatized back to the atmosphere. (Havlin et al. , 2005)

Nitrate ($N0_3^-$*)*

Nitrate is another inorganic plant-available nitrogen type. It is very soluble in water and is consequently highly mobile with water movement. It can be lost as N gases to the atmosphere through the process of denitrification in anaerobic conditions. (Havlin et al. , 2005)

Organic nitrogen

Organic N occurs as proteins, amino acids, amino sugars, amines, urea and other complex N compounds. These can be mineralized to plant-available forms by aerobic and anaerobic microorganisms (Havlin et al. , 2005).

Phosphorus

Phosphorus is one of the key limiting nutrients in ecosystems. Small change of concentration can cause big ecosystem changes. Phosphorus can also be found naturally in both organic and inorganic forms. Total P is the sum of organic and inorganic P forms. Phosphates (PO_4^{3-}), such as calcium- and orthophosphates are the inorganic, plant-available phosphorus forms found in wastewater. These are the dominating phosphorus forms found in excreta. Organic P can be broken biologically down to orthophosphates. (Jönsson et al., 2005)

Pathogens/Coliform bacteria

For checking the sanitary quality of wastewater, coliform bacteria are a commonly used indicator. Fecal coliforms such as *E. coli* and *Klebsiella* originate from the feces of warm-blooded mammals. Only certain strains of E. coli are actually pathogenic or harmful to human health, but they are however an indication of the possible presence of other harmful fecal pathogens. Total coliforms can include bacteria naturally found in the aquatic environment, in soil and on vegetation. Another pathogen, *Ascaris*, a parasite, is one of the most resistant pathogens that can occur in feces and thereby controls the extent of treatment. (WHO, 2006)

Metals

Metals like lead, arsenic and cadmium are all elements of relevance for the study. This is discussed further below.

2.2.3. Relevance of metal study

Heavy metals such as lead (Pb), mercury (Hg), zink (Zn), cadmium (Cd), iron (Fe), Arsenic (As) and copper (Cu) can be extremely harmful, especially in animals where they are bio-accumulated. A few, such as Cu, Zn and Fe are essential for both plants and animals in small concentrations, while Pb, Hg, As and Cd are toxic even at small concentrations. It is relevant to investigate certain metals because of health and environment criteria.

Heavy metals can reach humans through different routes. Pb, Hg, Cd are Cu are among those which can travel in the air from point sources like industries (Swedish EPA, 2011). In later years, improved technology and purification equipment have made it possible for industries to reduce contaminations in their emissions.

Lead is the most common of the heavy elements in the earth's crust, accounting for 13mg/kg earth, naturally occurring in several different isotopes. Modified versions of this metal have found its way into many areas of society. It is commonly used in plastic stabilizers, lead acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors, ammunition and glazes. The routes through which humans are mainly exposed are through air, tap water and food. Lead in air could depend on different factors, for example proximity to roads and point sources such as battery plants. Tap water often contains lead, to an extent from natural sources, but primarily from the household plumbing system, like from the piping, fitting, etc. Lead compounds can even leach out from PVC pipes in high concentrations especially in soft, acidic waters. Even soils and household dusts can be significant contributors of lead intake in small children. Since lead is immobile, it remains in soils or its environment unless actively removed, thus the top 5 cm of soil usually contain the highest concentrations. Lead has also been used widely in petrol but is currently forbidden in many countries due to its harmful effects on humans. (WHO, 2003)

In agriculture, common sources of cadmium are sludge, deposition from the air, mineral fertilizers, lime, etc. Of fertilizers used in the EU, the cadmium to phosphorus ratio ranges between 2 to 133 mg/kg phosphorus. The average cadmium content in fertilizers used in Sweden is 6 mg/kg phosphorus. The main route of Cd exposure in humans is through diet; the intake of Cd is proven to have negative health effects. Some of the Cd consumed stays in the kidneys, with the risk of causing kidney problems as well as other health problems. (Kemikalieinspektionen, 2011)

2.2.4. Toilet wastewater, graywater, urine, feces, fecal sludge

Graywater is a term used to describe all household wastewater excluding toilet water, it thus consists of wastewater from showers, baths, dishes, laundry, other cleaning etc. The concentrations of its components depend on water use. Table 3 shows average values of concentrations of different parameters when graywater production is approximately 200 liters per person and day. Since water usage in Bolivia is normally less (in Santa Cruz 150 liters per person and day (Degadillo, 2011)) the values are likely higher (more concentrated) than what the table shows.

Table 3. Typical graywater values according to Morel & Diener (2006), when graywater production is 200 l/person & day

Parameters	Typical values (mg/l)
TSS	100
BOD_7	150
Total-N	5
Total-P	10

Toilet wastewater is used in this thesis as a term to describe wastewater that includes flushed toilet water, i.e. including urine, feces and toilet paper. Toilet wastewater contains pathogens as well as nutrients.

Domestic wastewater is a term used for mixed total household wastewater, in other words the toilet water plus graywater.

Typical composition for European domestic wastewater is given in Table 4. Typical values vary for different countries and habits. Considering less water is used on average per person and day in Bolivia, it is possible that the concentrations of some parameters in Bolivia are higher. Unlike Europe however, since it is not typical for toilet paper to be disposed of in the toilet in Bolivia, this should result in a lower organic loading.

Table 4. Major constituents of typical domestic wastewater (Adapted from WHO, 2011)

	Constituent concentration mg/l		
Parameters	High load	Medium load	Weak load
TDS	850	500	250
TSS	350	200	100
Total N	85	40	20
Total P	20	10	6
Grease	150	100	50
BOD_5	300	200	100
Fecal Coliforms	normal: 10^6-10^{10} per liter		

Urine is the liquid waste produced by the body while *feces* refers to the semi-solid waste excreted from the body. Urine and feces have some typical characteristics, although the exact composition varies from person to person and in general varies between countries due to different diets. (Tilley et al., 2008)

Urine is a valuable source of nutrients. Urine includes significant amounts of nitrogen, phosphorous, potassium and sulfur, all readily plant-available in the same forms as in chemical fertilizers. 75-90% of nitrogen in urine is in the urea form during excretion, but 90-95% of urea degrades rapidly to ammonia, NH_4^+. Phosphorous is found mainly in ion-phosphate forms (PO_4^{3-}, $H\ PO_4^{2-}$, $H_2\ PO_4^-$) but also in precipitated forms. (Jönsson et al., 2004);(Pettersson & Kirchmann, 1995)

Other characteristics of urine to consider are the concentrations of heavy metals, pharmaceutical residues and pathogens. Urine is normally free from pathogens, but there are a few exceptions such as when cross-contamination by feces or rare pathogens like *Leptospira interrogans*, *Schistosoma haematobium*, *Salmonella typhi* and *Mycobacterium tuberculosis* are present. Although heavy metal concentrations in urine are very low, the potential for pharmaceutical residues to leave the body in active forms through urine is large. (Jönsson et al., 2004)

Feces do not contain as much nutrients as urine, but are nonetheless a valuable source of nutrients especially including significant amounts of phosphorous and potassium as well as organic matter. Of the nitrogen in feces approximately 50% is water soluble; most phosphorous is found as calcium phosphate; potassium is found as ions. (Jönsson et al., 2005)

Other qualities that characterize feces are that they contain bacteria, viruses and other pathogens; about 90% of ingested heavy metals and a large fraction of pharmaceutical residues leave the body in the feces. Fecal coliform concentration is between 10^7 and 10^9/100 ml. (Jönsson et al., 2004)

Fecal sludge (also referred to as *sludge* in this thesis) is a term used to describe the raw or partially digested solids which sediment out from the toilet wastewater, graywater, or fecal water. The composition, which varies largely depending on the input, location, storage etc., determines the possibilities of reuse. Nutrient, heavy metal and pathogen content may be high (i.e. Helminth egg concentration of up to 60 000 eggs/l). (Tilley et al., 2008)

2.2.5. Legislation

The laws and regulations of treatment requirements for different countries vary in their allowed discharge concentrations in wastewater. Some regulations are given for Bolivia and for the sake of comparison, also a few limits for Sweden.

Bolivia

The law pertaining to the water and environment sector in Bolivia is known as the Ley 1333. The RMCH (Reglamento en Materia de Contaminación Hídrica) is the section that concerns water and wastewater. This law classifies different types of receptors (A-D) according to the amount of treatment required in order to obtain a potential drinking water, where A requires little or no treatment and D requires most treatment. Depending on the classification, the limits for the permitted concentration of different substances in the water discharged vary. Some limits relevant to the investigation are given in Table 5.

Sweden

The Swedish regulations are different depending on the size of treatment plant and the location. For domestic wastewaters, the *normal* regulations for individual regarding the concentrations in wastewater discharged, are to reduce BOD_7 by 90%, and to reduce total P by 90%. The most common limits for wastewater discharged from big treatment plants are concentrations of 10 mg total N/l, 15 mg BOD_7/l and 0.3 mg tot-P/l. (Naturvårdsverket, 2006)

Table 5. Legislation in Bolivia and Sweden on permissible wastewater limits

Parameters	Legislation limits (mg/l)		
	Bolivia	**Sweden**	
	Clase C, D in A-2	Individual Onsite	Large treatment plants
TSS	60		
BOD_7		Approx. 30	10
BOD_5	80		
Grease	10		
Total N	12		15
NH_4^+-N	4		
NO_3^-	50		
Total-P	1	Approx. 3	0.3
Fecal coliforms*	$1{\cdot}10^3$		
Pb	0.6		
Cd	0.3		

* measured in MPN/100ml

2.3. ANAEROBIC AND AEROBIC PROCESSES

The lack or presence of oxygen benefits different microorganisms and different functions, so anaerobic and aerobic treatment processes have their advantages and disadvantages regarding removal of the formerly mentioned parameters. Since both carbon and nitrogen have gaseous phases as CO_2 and N_2 in normal conditions, these can be released into the atmosphere during treatment processes, leaving the wastewater cleaner. Phosphorous does not have a gaseous state, so the removal of phosphorous from wastewater depends on other processes[1]. While aerobic conditions facilitate the nitrification of NH_4^+ to NO_3^-, anaerobic conditions allow the nitrification of NO_3^- to N_2. For the removal of organic matter, brief descriptions of the digestion processes follow.

Anaerobic digestion

Anaerobic digestion of organic matter is a complex process with multiple steps and different types of microorganisms that play their part. The organic matter is broken down to methane (CH_4) and carbon dioxide (CO_2) through these steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The bacterial activity and biomass growth during each step depends on suitable conditions. They are sensitive to temperature and environment and to particular toxic compounds. They also have a slow start-up process.

There are different conditions that can cause the biomass to thrive. *Low-rate systems* are systems in which there is poor contact between substrates and biomass and therefore biomass growth and digestion is slow, while in *high-rate systems*, there is good contact between substrates and biomass leading to rapid biomass growth and faster digestion.

[1] Like in a leaching field, the P-removal depends on how much can be chemically sorbed to the system materials.

Good contact can be achieved by for example using filter media and a high sludge concentration is necessary.

An advantage of anaerobic digestion compared to aerobic digestion is that very little sludge is produced since anaerobic digestion does not produce as much biomass as aerobic degradation.

Aerobic degradation

In aerobic degradation of wastewater, oxygen provides microorganism with a source for respiration to break down the organic material to CO_2. Aerobic microorganisms require N in the substrate to thrive. In treatment systems such as leach fields, the filtering medium allows oxygen to enter.

2.4. GUIDELINES FOR DRINKING WATER

Only a handful of parameters were studied for drinking water. Some parameters were important even though they do not all pose health risks. Some WHO guidelines follow in Table 6.

Table 6. WHO drinking water guidelines for some parameters (WHO, 2011)

Parameter	Units	Limit	Remark
pH			Not of health concern at levels found in drinking water, but important operational water quality parameter
Alcalinity (CaCO3)	mg/l		Not of health concern at levels found in drinking water, but may affect acceptability of drinking water
Fecal coliform	MPN/100ml	0	(According to European directive)
NH_4^+-N	mg/l		Occurs in drinking water at concentrations well below those of health concern
NO_3^-	mg/l	50	
TDS	mg/l		Not of health concern at levels found in drinking water, but may affect acceptability of drinking water
Total Fe	mg/l		Not of health concern but may cause acceptability problems
Manganese	mg/l		Not of health concern but may cause acceptability problems
As	ppm	0.01	
Cd	mg/l	0.003	(From agricultural and industrial activities)
Pb	mg/l	0.01	

3. METHODS

The methods of the investigation included several steps: determination of the objective; background and literature studies; fieldwork to gather data and assess the current and future situation; the designing of a system based on literature, fieldwork data, calculations and specific conditions; documentation and sharing of the results. In this section, the methods for fieldwork and data assessment are described.

3.1. FIELD STUDIES – SURVEY OF PRESENT CONDITIONS

Data concerning present conditions was collected in order to have a reference point for designing the system. Water and wastewater flows from the farm households and activities were quantified; the quality of wastewater was determined; physical and ecological conditions and relevant farm activities were observed and documented.

3.1.1. Water flows

To determine the water flows on the farm, four different methods were used.

- Water meters: Water meters were installed (Figure 4) with the help of the farm technician in key places to register water flows in a total of eight places. Protocols in which to record the data were created. Daily wastewater flows were recorded manually during a period of two months. In order to facilitate the collection of more data, a farm inhabitant was trained to assist in recording data. This was a big help especially during days that I could not be present at Ceasip. However, some days were skipped or recorded poorly, and consequently excluded from the results. During one day, hourly wastewater flows were also registered.
- Observations: Water was used in some places where there were no water meters. Such activities were observed when possible (i.e. irrigation of certain fields and lawns) and flows were estimated by adding up the amount of time that taps were open and comparing to known flows.
- Interviews: To make reasonable estimations and guesses, interviews with farm inhabitants and employees were made to get an idea of habits and routines. This was done more extensively for three households at Ceasip and briefly for two households.
- Bucket and timer: Some water flow estimations were made based on the time it took to fill a bucket with water to a known volume. This method was used to get an approximate figure until the water meters were put in.

Finally, the data from the different sources was transferred and combined in spreadsheets, calculating averages and making other necessary calculations and assumptions to get an overall picture of all the water flows on the farm. The flows considered were water used (tap water/well water), wastewater collected, and waters lost (waters used but lost without collection). Explanations and assumptions made for the calculations are stated in the Appendices 2 and 3.

Figure 4. Installation of water meters at Ceasip with employees.

3.1.2. Water quality

To determine the suitability of using the wastewater in irrigation or of other disposal methods, previously mentioned parameters were analyzed. Due to various reasons such as limited time and financial limits, not all characteristics of wastewater were analyzed in the investigation. Table 7 displays some limitations made.

Table 7. Limiting of parameters in the investigation

Parameters	**Analyzed**	**Reason for limited choice**
Macronutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium)	Only Total N, some NH_4^+ and $N0_3^-$; phosphorus	The most limiting nutrients in plant growth. Although $N0_2^-$ is toxic, normally insignificant concentrations at neutral pH (Havlin et al. , 2005).
Some micronutrients (iron, manganese, barium, copper, zinc, Mo and cobolt, and manganese)	Only manganese	Suspected high concentration in farm water (observed black sediments and employee statement) and its potentially harmful qualities in equipment and pipes
Trace elements (i.e. fluoride and boron)	None	No detected sources of possible input in considerable concentrations at Ceasip nor "spots" on teeth
Element metals and heavy metals (i.e. Pb, Hg, Cd, Zn, Fe, As)	Only Pb, Cd, As	Toxic in low concentrations, higher probability of occurrence in wastewater
Hazardous substances (medical residues, endocrine disruptors, pesticides, persistent organic pollutants)	None	Very small quantities, policy of minimum use of medicines with the cattle and minimum application of pesticides on crops, cattle mostly in fields
Organic matter	Only BOD (with a few exceptions)	Sufficient to observe the BOD and COD can be calculated approximately if the BOD is known, exceptions made for quality control

Samples were taken from around the farm on several occasions (see Figure 5) for the analyses. Not all places (like bathroom by stable and Casa Milanio) were analyzed since it was assumed that the other buildings were representative enough of the quality. The drinking water from the tap of Casa Huespedes was assumed to be representative for all the drinking water on the farm that has to travel through the distribution net before arriving at the tap. The microbial water quality was also checked for the deep drilled well directly upon leaving the ground, and before entering the storage tank or the distribution net.

Figure 5. Sampling wastewater at Ceasip.

Some parameters were registered onsite with portable equipment while some parameters were analyzed at the UTALAB laboratory in Santa Cruz. The salinity of the waters and wastewaters was calculated from in situ measurements of conductivity. Since the amount of tolerable salinity depends on the crops and on whether or not the salt is washed out regularly, the soil types and crop types were also considered. The pH was tested in situ to assure that wastewater was not too acidic or basic to be reused as irrigation water. The heavy metal content of wastewater was analyzed in laboratory to control that it does not exceed limits of recommendation for irrigation water. The nutrient content of the water was analyzed in laboratory to determine the suitability for crops, especially regarding N concentrations.

UTALAB is a laboratory certified with the ISO 9001, affiliated with the University Gabriel Rene Moreno. To assure the precision of the laboratory analyses, samples were labeled with minimal information (only a number) to prevent prejudice during the analyses; duplicates of certain samples were taken and turned in with different numbers;

a solution of a “known P-concentration” was also turned in. (See *5.3. Data Accuracy*.) Table 8 gives the analysis method for each parameter.

When some results for certain parameters proved to be non-accurate and unreliable, like total N and total P, permission to enter the laboratory was solicited to observe the methodology. Together with the employees, certain analyses were redone or exchanged for other analyses. Unable to detect the causes of the poor results, problems remained, and so these results are marked as especially unreliable in Appendix 5 and *not* used as a basis for conclusions.

Table 8. Analysis methods used by UTALAB

Parameter	Unit	Analysis method	Resolution or detection limits
Temperature*	°C	Digital thermometer	0.1
pH		Digital pH-meter	0.1
Conductivity*	µS/cm	Digital conductivity meter	1
DO*	mg/l	Digital oxygen meter	0.1
Fecal coliforms	MPN/ 100ml	Multiple-tubes fermentation technique. Various dilutions are made and placed in different tubes. Tubes with bacterial growth are counted after incubation to acquire the sample concentrations.	1.1
BOD_5	mg/l	Respirometric using mercury filled columns in tubes. Each incubated, airtight sample moves a mercury column according to how much oxygen is consumed.	4
COD	mg/l	Cromo-sulphuric oxidation and photometry	20
Greases	mg/l	Soxhlet extraction and gravimetric. The grease is extracted in the Soxhlet with the aid of a solvent and heat then weighed.	1
Total P	mg/l	Molybdate method	0.15
Total N	mg/l	Kjehldahl: Digestion, distillation and titration	5
NH_4^+-N	mg/l	TNT Cuvette test[1] and photometry	0.015
NO_3^-	mg/l	LCK Cuvette test[1] and photometry	0.23
TDS	mg/l	Gravimetric. The sample is filtered through a 0.45-microns filter, dried and weighed.	1
TSS	mg/l	Gravimetric. The solids in the sample that do not pass through the 0.45-microns filter are dried and weighed.	1
As	ppm	LCK Cuvette test[1] and photometry	0.002
Cd	mg/l	LCK Cuvette test[1] and photometry	0.02
Hg	mg/l	LCK Cuvette test[1] and photometry	0.001
Pb	mg/l	LCK Cuvette test[1] and photometry	0.1

* *In situ* measurements made with portable equipment brought from Sweden
1. TNT and LCK Cuvette tests are standard tests produced by Hach-Lange with ready-made reagents. For more details see *http://shop.hach-lange.com/*.

3.1.3. Physical conditions

Physical conditions of the Ceasip property with relevance to the project were determined in different ways.

- Slopes, areas and topography: by maps and observations. It was necessary to investigate the slopes of the property in order find an appropriate location of wastewater treatment. It would be preferable to use the natural slope of the property to lead away wastewater so as to minimize the need of pumps and the use of electricity. Maps were used to see approximate areas of lagoons and farm sectors.
- Groundwater level and flow: Groundwater levels on the property in four existing wells was measured and compared on one occasion. Also, employee knowledge about the groundwater flow direction and topographic maps was used. The depth down to the ground water table, the direction of the groundwater flow, and qualities of the geological bedrock are of interest to determine the risk of contaminating that water as well as potential health risks and environmental risks involved.
- Soil types from soil report by Agroconsult from 2006 and observations. The soil type, different qualities of the soil in combination with wastewater flows, and wastewater quality were used to determine the relevance of different types of treatments and the relevance of potential reuse methods.
- Hydraulic conductivity: Percolation tests were carried out as follows: Three different pits were dug to a depth 50-60 cm in appropriate locations. These were filled with water, allowed to saturate and then refilled. The times and new depths to water surface were recorded at regular intervals. Finally, both separate and average percolation rates were calculated from the recorded times and distances.
- Climatic conditions: By using data from *Informe Técnico 2007-2009* (Ceasip, 2009) compared to data from Agroconsult's soil report, both based on Bolivia's national meteorological and hydrological service (Senhami) data
- Farm activities and production: through on farm experience, technical Ceasip report, and information provided by Ceasip employees and directors

3.1.4. Investigation of sustainability criteria in present conditions

The sustainability criteria for environment, health, socio-culture, technical function and economy were investigated to some extent for the present conditions.

Environment

Focusing on the main sustainability criteria previously mentioned (protection of groundwater from contamination, reduction of water usage and recycling of nutrients) literature studies and calculations were done to be able to decide the potential importance of reusing water and nutrients. Nutrient flows were calculated according a method described in *Guidelines on Use of Urine and Faeces in Crop Production* (Jönsson et al., 2004) and crop water needs were calculated according to data from Browner & Heibloem (1986).

Environmental criteria regarding water flow and water qualities are previously described. The risk of contamination of groundwater was judged by determining the depth to the groundwater table, the depth of the current soak pit system and the quality of the wastewater. Some consideration was also taken to seasonal changes.

Although eutrophication was a problem in some parts of Bolivia, it was not studied specifically here because of the large distance from Ceasip to large natural water recipients like rivers or lakes. Gas emissions and acidification were also excluded from the study. The consumption of energy and resources in the current system was only generally estimated by quantifying water consumption. A specific study of electricity consumption on farm was not done. Actual levels of contamination by chemicals and heavy metals from chemical products used for cleaning, fertilizers, pesticides and medicines could not be determined in the given time frame or with the laboratory methods available at the UTALAB.

Health

Various methods used to investigate the current health risks of the sanitation system were through the observation of the potential transmission routes of pathogens, observed hygiene and health of the people on the farm, conducted interviews, and analysis of the drinking water in laboratory. The pathogen content of the wastewater was analyzed by doing a laboratory microbiological analysis of coliforms. The general direction of groundwater flow was assumed from the slopes observed on topography maps and local knowledge. Potential health risks due to groundwater quality in the future were considered.

Socio-cultural

To understand the socio-cultural aspect of water and sanitation in a local context, and attitudes towards sustainability, interviews were carried out and some case studies were reviewed about other failed and successful sanitation projects in Bolivia. The social acceptance of current and proposed ideas was considered by investigating attitudes of most individuals living on farm regarding relevant collection, treatment, and technology by means of simple interviews. Some interviews were more formal with questions and answers written down while some were semi-formal. Field trips were also made to several sites in order to better understand acceptance issues of sanitation systems. Sanitation systems were observed on a local, regional and national level.

Technical function

The technical functions of the current system were observed on several occasions by guided walkabouts from the farm technician. Maintenance was performed and documented together with the employees such as the cleaning of the sewer system.

Economy

Due to some poor technical function to replace/repair some old parts of the present system, maintenance and operational costs were observed to be necessary. Costs for drinking water, fertilizers and electricity in Santa Cruz were investigated by speaking with Saguapac and venders and by doing Internet research. Other economic aspects for the present system were not specifically investigated.

4. SITE DESCRIPTION

In this section, the site is described to provide the reader with a better understanding of the methods involved as well as comprehend the context of the results.

4.1. REGIONAL

4.1.1. Location

The Ceasip is located 18 km south of the city center of Santa Cruz de la Sierra (see star on map in Figure 6). The research farm was created in 1996 and is now in a peri-urban area, with the expanding city getting closer and closer to the property boundaries. With Ceasip's closeness to the city, this means that many of the conditions for the city are the same for the farm or highly relevant for a near future. The city drinking water services from a distribution net have already reached many homes only a couple kilometers away from Ceasip.

Figure 6. Location of Ceasip in relation to Santa Cruz (Source: Modified from Google maps, 2011, with permission).

4.1.2. Sanitation and drinking water

The city of Santa Cruz de la Sierra reaps the benefits of the world's largest consumer owned cooperative, Saguapac. Saguapac, which is certified with the international ISO

9001 for quality, is in charge of water supply and provides sanitation services. Saguapac faces many challenges and despite the company's efforts, many problems persist. Over 1 million inhabitants have access to the safe drinking water in their homes from the water distribution net; according to the Lic. Cèsar Flores, in charge of Saguapac's social responsibility sector (2011), the average water usage per city inhabitant is 150 liters per person and day; while approximately only 640 000 inhabitants (1/3 of the inhabitants) are connected to the sewage system. The company is expanding the area of its services, but it may take several years to provide the current urban areas with sewers and improved sanitation and maybe even 10-15 years to reach what are currently the outermost rings of the city. With such a time lag for sanitation service expansion, it is important that in the meantime peri-urban homes take care of their own wastewater responsibly to avoid groundwater contamination and other problems.

Wastewater treatment in Santa Cruz allows wastewater quality to become significantly improved before being let out to the river recipient, Rio Piraí. Treatment is carried out at several different locations through a series of four artificial ponds, namely an anaerobic pond, a facultative pond and two maturation ponds (Saguapac, 2011). Biogas is collected and burnt on-site from the first anaerobic pond. The BOD is reduced from 300 mg/l to 30 mg/l and pathogens are reduced by 99.9% (Ing. Fernando Ibañez, 2011). However, a large portion of nutrients such as nitrogen and phosphorous are not removed. Over 2/3 of the city's population which is not connected to the sewage system, either have a septic tank or pit from which the wastewater percolates into the soil, or they throw out the wastewater directly to ditches and streets. In the latter case, much of the wastewater reaches the same river recipient, the Piraí, along with the pluvial run-off waters. The Piraí is therefore burdened by high loads of nutrients as well as other contamination. Even local newspapers, such as *El Deber,* warn the inhabitants of the contamination caused by the city´s wastewater problems.

The city´s drinking water usage and management is not sustainable. It is estimated that the rate of extraction from the groundwater supply will exceed the replacement rate within 10 years (Salmón, 2010). Groundwater can be found at shallow depths but the aquifer used for water supply is found at depths sometimes over 300 meters down. The water supply is already at risk of contamination so it is important that the wells for drinking water supply are very deep (some reach as far as 350 meters) and are away from the sewer system. (Saguapac, 2011)

4.1.3. Groundwater contamination

In Santa Cruz there is a major problem of soil and groundwater contamination. The ground water under the city is contaminated down to 100 meters depth. There are many sources from which the contaminants proliferate. The main source of contamination is soak pits (see *6.6.3. Soak pits.)* Other contamination sources include curichis (degraded, trashy wetlands), unlined channels, poorly constructed wells (without sanitary seals), ponds, landfills and gutters. The types of contaminants stemming from all these sources include physical, chemical and biological contamination. The increasing population and industrial growth, and their excessive production of trash are factors affecting the continuous generation of more contamination. (Saguapac, 2008)

The safety of Ceasip's groundwater supply is at risk. With the rapidly expanding city and the continued contamination of ground and surface waters in Santa Cruz, it is only a matter of time before Ceasip's groundwater well at 95 meters depth also receives contaminated waters.

4.1.4. Climate effects

Bolivia has a varying climate due to the extreme variations in altitude. Lower altitudes are humid and tropical while higher altitudes are cold and semiarid (CIA, 2011). Bolivia has two main seasons, with the warmer and wetter summer months lasting from November through March, and the drier and colder winter months are typically from April through October.

According to a report on Ceasip soils by a consulting company Agroconsult (2006), there appears to be an excess of water in the tropical region of this study during the summer months and a deficit of water during the winter months. There is an imbalance in water availability during the year considering variations in temperatures, precipitation and evapotranspiration. With an altitude between 408 and 415 meters, the average annual temperature is 24.6°C. In a historical perspective (66 years of data), summer months have an average around 27°C while winter months have an average temperature as low as 20°C. The average annual rainfall for Santa Cruz is 1241 mm, although from year to year, great variations can occur (like in 1981 with 2116 mm and in 1970 with 712 mm). These values give a monthly average of 104 mm. (Agroconsult, 2006)

A technical report about the Ceasip by the Foundation Simon I. Patiño (2009) confirms the climatic statements above by using data retrieved from the weather station monitored by Senamhi located in the city at the airport, El Trompillo, 15 km north of Ceasip. Other sources state that the last 20 years held greater variability of extreme rainfall or draught (Barber, 2006). Drought months have forced the farm to irrigate certain crops while the wet months have caused flooding and forced the farm to dig ditches across the property for drainage of excess water. (Ceasip, 2009)

Because the main objectives of this study do not include a specific water balance study, the data on the decreasing availability of a high quality water source are considered sufficient to justify the importance of sustainability criteria regarding water reduction and reuse of water. Evaporation from Saguapac treatment ponds is around 10% (Ing. Fernando Ibañez, 2011), which is why the same assumption will be used even for Ceasip surface waters.

While previously, the farm received run-off waters during heavy rains from adjacent properties and from the outskirts of the city which contributed to flooding of the property, now more channels have been constructed which should steer a greater majority of such waters away from the Ceasip property. Of the total municipal budget for investments, 15% (120 million dollars) is destined for drainage channels until 2015, which is estimated to be enough to resolve the city's current drainage problems (Salmón, 2010). Consequently, flooding problems in the city and at Ceasip should be smaller in the future.

4.1.5. Soils and vegetation

Soils and vegetation in Bolivia vary greatly depending on the region so only the lowland eastern regions are studied here. The lowlands are divided into several river valleys. The soils have been formed by alluvium materials (deposited by the rivers) and windblown materials deposited in different volumes throughout various eras, which has resulted in infertile, patchy, variable soil types containing much sand and clay.

The soils and vegetation are fragile, threatened by desertification. They are characteristically poor in nutrients and alternate between dry and waterlogged (Nationalencyklopedin, 2011). Soil degradation has been an increasing problem in the lowlands, especially in annual cropping areas, both naturally and technology-induced. Available soil moisture has decreased caused by the large percentage of soils which have been moderately or severely compacted causing the loss of water pores and air storage pores, the incorporation of windblown fine sand deposits and the loss of organic matter. Surface crusting, restricted rooting and reduced rainfall infiltration have been the results from this. (Barber, 2006)

In the Ceasip farm zone, three main soil types have been identified, namely clay soils covered with a thin layer of wind deposited material, deep sandy soils, and poorly drained clay soils. (Córdova et al., 2010) Just south of the farm by a few km, northerly winds influenced the formation of sand dunes, "Lomas de Arena" (Agroconsult, 2006).

Figure 7. Left: Desert conditions right up against vegetation near Ceasip at "Lomas de Arena"; Right: Waterlogged soil beside dry soil.

According to the investigation conducted by Agroconsult on Ceasip soils (2006), results varied for different areas, but generally showed the following characteristics:

- Conductivity/salt levels low to normal
- Organic matter and nitrogen generally low but some parts medium. Organic matter decreases with depth. 10 cm: 2.5%, 100 cm: 0.5%
- Phosphorus, most parts low/very low but some parts medium/high.
- pH, generally low (between 4.5 – 6)
- Varying soil texture: Sand (53-80%), Silt (12-25%), Clay (5-20%)

Patches of transitional forest between Amazon forest and the Chaco forest formed the original vegetation of the Ceasip property. Since the high sand content in some sectors decreases water retention, growth of perennial arboric vegetation is limited especially during periods of drought. (Agroconsult, 2006) As shown in Figure 8, the Ceasip property conserves 70 ha of native forest that is currently in the process of recuperation and natural succession. Other parts of the property accommodate both native and introduced species in fields, pastures, cultivated crops and gardens. (Córdova et al., 2010)

Figure 8. Ceasip farm property in red. (Source: Google map, 2011, with permission).

4.2. CEASIP FARM – PRESENT CONDITIONS AND FUTURE PROJECTIONS

Ceasip property is currently 140 ha of which approximately half is forest. The buildings of the farm are all located on the western wing of the property, an 8-12 ha, thinner section. With the future expansion, new buildings will be built slightly northeast of the current ones.

Land use	Area (ha)
Crops	17
Pastures/fields	33
Fruit&Veg. Gardens	3.5
Gardens + infrastructure	16.5
Forest	70
Total	140

Figure 9. Land use map at Ceasip (Source: Fundación Simon I. Patiño (2009))

4.2.1. Activities/sectors of the farm

The activities/sectors of the farm with special relevance to water management are the following:

- Households, office, cafeteria, mechanical shop
- Dairy factory
- Stable (calves and milking)
- Cattle drinking water
- Fruit & vegetable garden, fields
- Groundwater, distribution net and water receptors

A brief description of the farm activities and sectors follows, including future projections after the expansion. The future plans are not all “set in stone,” so the future projection numbers should be seen as estimations. The numbers stated are used as a basis for subsequent calculations while other information is used as a basis for assumptions and to give the reader an understanding of the conditions.

Households, office, cafeteria, mechanical shop

The Ceasip property is the home for several employees and their families. Approximately 20 people live on the farm. There are 26 employees who work Monday through Saturday of which four live on the farm with their families and a few cowboys take turns working and living every four days on the farm. Ceasip also receives investigators and temporary employees to complete certain tasks, as well as other visitors, sometimes even large groups such as university students. The amount of extra people and visitors can be estimated to 30 people per month. Six people normally work in the office, but there is often a flow of people in and out of the office throughout the workday.

The activities pertaining to water and wastewater, in and around the buildings, are bathroom use, cleaning of laundry, washing vehicles, use of kitchens, general cleaning, and watering of the lawns/garden. The office bathrooms are mainly used by the office workers and visitors, while most of the other employees relieve their needs out by the fields closer to their work during the day, or they use another bathroom in mid-property. Laundry is cleaned regularly throughout the week, both by hand and by washing machines. A cafeteria/kitchen, which is currently part of a household, is used to make lunches for all the employees and some visitors, Monday through Friday. Some water is used regularly for cleaning indoors and outdoors. During the dry season, some lawns and gardens outside of the houses are watered. In the mechanical shop, water is normally used every Saturday for washing vehicles externally. (During the wet and dirty season, vehicles may be washed up to every couple days.)

Since the future projection for the farm buildings is an expansion that will allow an approximate doubling of capacity, it is projected that 60 visitors will be received per week. The cafeteria will be built as a new building by the current office building.

Dairy factory

The Ceasip farm has a small dairy factory where approximately 10 000 liters of milk are taken care of yearly and yoghurt, cheese, butter and ricotta cheese are produced. Much water consumed used is for cooling in certain processes and cleaning. Antibacterial cleaning chemicals are used regularly.

The future projection is to have a new dairy factory building that will allow an approximate doubling of capacity 20 000 l/year. This also means that up to twice as large water usage and wastewater production is assumed.

Stable (calves and milking)

The cattle are only in and around the stable during milking and evening/nighttime hours. Otherwise they are out in the fields. The stable has a milking room as well as a bigger room with stalls for calves. Cows are milked daily at 3.30 and 17.30. There are about 45 cows of which around 10 are milked. About half of the milk is given to the calves in their stalls while the rest is taken to the dairy factory. For the cowboys who milk the cows, hands are washed frequently throughout the milking routines and a general cleaning of the floors and stalls is done afterward. Hands are washed with a disinfecting soap containing triclosan while floors are only washed with water. A disinfection of stable floors and walls is done every 15 days by hot flame rod and spraying a disinfecting chemical (Sterilón, which contains dimethyl benzyl ammonium chloride and isopropyl alcohol).

Most of the manure from the stable is shoveled out and let to dry, thereby avoiding much loading of organic material in the wastewater. The manure is collected after it is dry, then composted on property.

The future projection is to have approximately 90 cows and a new stable will be built. This means that up to twice as large water usage and wastewater production can be assumed.

Animal drinking water

On Ceasip, three horses and the cattle drink water from plastic and cement troughs.[1] This water is changed every four days. Typically, about 50% of the water from the cement troughs is poured out directly into the soil so that the trough can be scrubbed before being refilled.

Drinking water is taken to the fields every four days to fill plastic troughs of which most is consumed by the animals. During hot periods, it can sometimes be necessary to refill the drinking troughs in the fields after only two days. Since the future projection is to have more animals, more drinking water will be consumed.

[1] The amount of water the animal stock consumes varies widely depending on climatic conditions, age and size of the animal, and its lactating state. A cow drinks on average anywhere 40-140 liters of water daily while a calf consumes 25-50 liters daily. A horse consumes 40-50 liters daily. (NSW DPI, 2007)

Figure 10. Left: Animal drinking water troughs; Center: Fruit and vegetable gardens; Right: Employee working in field.

Fruit & vegetable garden, fields

Of the 140 ha property, about 3.5 ha are fruit and vegetable gardens (Figure 10). There are typically two employees working fulltime in the gardens, while other employees join when help is required to harvest. Some vegetables produced are tomato, eggplant, cucumber, asparagus and carrots among others. Most of the fruits produced are citrus fruits, like mandarins, oranges, lime etc., but there are also others like mango, papaya and bananas.

There are many different fields and pastures around the property with different types of crops such as grains and grasses for fodder (Figure 10), like sorghum and corn. The grain yield (year 2008) was for *Sorghum Massa* 4.15 tons/ha and for *Maize Chiriguano* 2.5 tons/ha (Ceasip, 2009).[1] There were also crops destined for human consumption, such as yucca.

Fertilizers and pesticides are used to some extent. The production of fruit, vegetables and field crops at CEASIP, require fertilizers, especially considering the low-nutrient soils. The farm uses several different fertilizers, namely compost, chicken manure and mineral fertilizers. Soil samples from the fields are often analyzed to decide what fertilizer is most needed. Some research is done at Ceasip to compare the effects of different types of fertilizers on production. The application of nonorganic fertilizers (i.e. urea, diammonium phosphate and triple 15 (N-P-K)) in fields was typically between 100-200 kg/ha. The best results were often produced where organic fertilizers (like compost) had been combined with nonorganic fertilizers. The application of organic fertilizers was typically 20 tons/ha. For example, for the cultivation of *Sorghum Massa* in poor, sandy loam soils like at Ceasip, it was recommended to use 100 kg/ha of triple 15 combined with 20 tons/ha of organic fertilizer. (Ceasip, 2009)

The fruit and vegetable gardens are dependent upon irrigation by hoses, especially during the dry season, October – December. The irrigation water is supplied by the deep well on the property, the same well that supplies drinking water. Normally, water for irrigation is used 1-3 times a week, but during the dry season, water is used nearly every day. A laborer manually moves the hose along the crop rows (Figure 11).

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[1] National average yields for Bolivia (dry grain yields) are 3.3 tons/ha for sorghum and 2.8 tons/ha for maize (FAO, 2009). However, these cannot be directly compared to Ceasip conditions because of the widely varying climate and geomorphic conditions in Bolivia.

In the future, the gardens may be moved a bit to make way for buildings. There will also be some research garden lots started on the west side of the farm to see the progress of different crops.

Groundwater, distribution net and water receptors

Fresh ground water/well water is used for all the farm activities requiring water. Water quality is tested periodically. The drilled well is to the northeast of the buildings. A PVC plastic pipe holds the well open. It has a depth of approximately 95 m with an inner diameter of 4 inches and surrounded by a sand filter of a thickness of another inch. It uses a submersible pump at 18 m depth that pumps the water up to a water tank at a height of about 9 m. The water tower tank has a capacity of 5 m^3 (Figure 11.)

This water distribution network at Ceasip is still the same system as from when the buildings and farm were first constructed. There are no drawings of the distribution or pipes. However, the farm technician knows the system quite well. Most pipes are laid underground at a depth of 10-40 cm. Sometimes leaks are found and repaired. The 3-inch tube leading the water out of the water tank splits off into thinner tubes for the distribution net. One side splits off to irrigation (there is also a tap for filling containers to give water to cattle), while the other side of the split goes to households, office, stables and factory. The network divides up into smaller tubes, entering the buildings in ¾ inch and ½ inch tubes.

Figure 11. Water distribution at Ceasip. Left: Water tower; Middle: Hose and tap for manual watering; Right: Water distribution net as it passes a water meter and then enters the building.

Other older wells exist on the property, about seven meters deep. They are not currently in use. There is one other underground water storage chamber, used to irrigate gardens around the houses etc. It has its own separate pump and distribution. Usually a sprinkler is used. There are about eight taps from this smaller distribution network.

According to the farm technician, the ground water table can reach a depth of up to 1.5 m below ground surface after heavy rains and much deeper otherwise.

There are several "lagoons" (low points on the property where water from runoff and rain collects) of which some are easily accessed and others are deeper in the forest. The lagoon of highest interest in this study is the northeast lagoon, which is also the largest. Its area is very roughly estimated to 2 500 m^2 and water holding capacity volume approximately 2 500 m^3. There are also several channels across the property (see Figure 9) leading surface water to the lagoons.

4.3. NUTRIENT FLOW CALCULATIONS

The nutrient flows are especially important for the environmental sustainability criteria, calculated here according to a method described in *Guidelines on Use of Urine and Faeces in Crop Production* (Jönsson et al., 2004).

The equations for calculating the N and P content in excreta according to diet are the following:

Equation A: $N = 0.13 \cdot \text{total protein}$

Equation B: $P = 0.011\ (\text{total protein} + \text{vegetable protein})$

The protein content in the Bolivian diet was taken from food statistics by FAO (2010) for Bolivia (compared to Sweden and Uganda):

Table 9. Food statistics from FAO (2010) for Bolivia compared to Sweden and Uganda. Percentages are out of dietary energy supply.

	Bolivia	(Sweden)	(Uganda)
Dietary energy supply (kcal/p&day):	2090	3110	2220
FOOD TYPES			
Carbohydrates	71.3%	50.7%	74.2%
Protien	10.8%	13.7%	8.8%
(animal protien)	(4.3%)	(9.1%)	(1.8%)
Fat	17.9%	35.6%	17.0%
Total protein (g/p&day)	56.3		
Animal protein (g/p&day)	22.6		
Vegetable protein (g/p&day)	33.7		
Fat consumption (g/p&day)	41.6		

Total excreta nutrients

- Equation A and the table value give N = 7.32 g/p&day (2.67 kg/p&year)
- Equation B and the table values give P = 0.99 g/p&day (0.36 kg/p&year)

Excreta nutrients per workday

It was assumed that on average 1/3 of their daily excreta could be collected per workday[1]. A workday is defined here as the approximate 9 hours of the day that an employee spends at Ceasip.

This would give: N = 2.44 g/p&day

P = 0.33 g/p&day

Urine nutrients per workday

Assuming that 87% of N is found in urine and the rest in feces while 70% of P is found in urine and the rest in feces,[2] that gives the following N and P values in urine that can be collected per person and workday.

N_{urine}= 2.12 g/p&day

P_{urine}= 0.23 g/p&day

<u>Office/public restrooms</u>

The values according to calculations above are used to calculate the nutrient flows in urine for all employees and visitors during one year and for 52 weeks in a year.

Employees
For approximately 25 employees @ 5.5 workdays per week, this gives the following yearly nutrient flow in urine on the farm[3]:

- $N_{urine}= 25 \cdot 5.5 \cdot 2.12 \cdot 52 = 15.16$ kg/year
- $P_{urine}= 25 \cdot 5.5 \cdot 0.23 \cdot 52 = 1.64$ kg/year

Visitors
With future considerations to receiving more visitors per week and assuming that each visitors spends less time on the farm than an employee during the day, and therefore that only 2/3 of the urine can be collected for visitors compared to employees. For receiving about 60 visitors per week we have the following nutrient flows in urine:

- $N_{urine}= 2/3 \cdot 60 \cdot 5.5 \cdot 2.12 \cdot 52 = 24.25$ kg/year

[1] This may or may not be reasonable for the future, since currently many employees seem to prefer to do their needs outside closer to their work field. It is also possible that many employees use the toilets without wanting to "admit" it.
[2] These percentages may vary. Here they are based on data from different countries in *Guidelines on Use of Urine and Faeces in Crop Production* (Jönsson et al., 2004).
[3] One employee may be sick or absent from, which is why not all employees are counted.

- P_{urine}= 2/3·60·5.5·0.23·52 = 2.63 kg/year

Households

For a household, the calculations vary a little. Assume that 2/3 of the *total* excreta nutrients are collected and that an average household has 5 persons. This gives the following nutrient flows in urine:

- N_{urine}= 2.67·2/3·0.87·5 = 7.74 kg/year
- P_{urine}= 0.36·2/3·0.70·5 = 0.84 kg/year

TOTAL COLLECTABLE NUTRIENT FLOWS IN HUMAN URINE AT CEASIP

The nutrients from office/public restrooms and 5 households are added together.

- N_{urine}= 15.16+24.25+5·7.74 = **78.1 kg/year**
- P_{urine}= 1.64+2.63+5·0.84 = **8.48 kg/year**

Nitrogen remaining in wastewater

The implementation of urine separation at Ceasip would reduce the nutrient load in the remaining wastewater. Assuming that 87% of the nitrogen in the wastewater comes from urine and if 65% of urine is successfully separated out from wastewater through implementation of urine separation, this would leave 100%-87%·65% = 43% of the total nitrogen in the wastewater. This very approximate percentage can be applied on the water quality results to get an idea of the remaining nitrogen concentration.

4.4. WATER NEED CALCULATION

Table 10 shows the water need for a typical crop at Ceasip, sorghum according to Browner & Heibloem (1986).

Table 10. Values for crop water need and grow period according to Browner & Heibloem (1986)

Crop	Water need (mm/total growing period)	Duration of grow period (days)
Sorghum	460-650	120-130

Using these numbers for sorghum gives an average water need per day of 3.5-5.4 mm (=3.5-5.4 liters/m^2). In practicality however, these quantities of water are not required for irrigation due to rain/climactic factors. With an average of 104 mm of rain per month, this could be just enough to fulfill the lower limit of the crop water need. However because of the uneven distribution of precipitation throughout the year with draughts and floods, the water need is greater at times and lesser at others.

5. PRESENT CONDITIONS RESULTS AND DISCUSSION

Taking into account the conditions stated previously in the site description and methods, results for present conditions and some calculation results are given and discussed in this section.

5.1. PRESENT WATER AND WASTEWATER CONDITIONS

The water at Ceasip that was used but not collected as wastewater was defined as water "loss." There are many activities/sectors of the farm in which water was used but no wastewater collected. These activities were for example irrigation, drinking water for animals, washing of vehicles, open faucets/leaks and cleaning. Water "losses" are listed in Appendix 2. The wastewaters that are collected for discharge in some way are listed in Appendix 3. A summary of water used in May and June 2011, whether lost or collected, is shown in Table 11. It is clear that the activity of the farm that required most water during the time of the investigation was irrigation of gardens, fields and lawns.

Table 11. Monthly water usage and the percentage of total use that each group represents

Ceasip water usage (m^3)				
	May	**June**	**Average monthly**	
Buildings	184	168	176	21%
Irrigation	598	596	597	71%
Animal drinking water	73	66	69	8%
Vehicle washing	2	2	2	0%
Open faucets	5	0	3	0%
Cleaning etc.	1	1	1	0%
TOTAL	863	834	848	100%

A description of the results follows pertaining to water and wastewater management and flow of nutrients in the farm sectors previously described.

5.1.1. Households, office, cafeteria

The wastewater from the eastern buildings is the main focus of this study for several reasons. In general, the domestic wastewater production on the Ceasip farm is the largest contributor of wastewater (even larger than the dairy factory and stable). Next, the topographic conditions would allow the wastewater from the four most eastern buildings (which currently include three households, the office and the cafeteria, shown in Figure 2) to be collected jointly using gravity. Finally, the current system (which already connects three of the buildings, as shown with black lines in Figure 29) is likely posing environmental threats and health risks as it uses a deep soak pit.

As stated in Table 11, approximately 21% of the total farm water usage is used for the buildings. In Figure 12, results for usage in May and June are shown for six different water meters at named buildings as well as an estimated usage at Casa de Milanio. For two of the buildings, there is an extreme increase in usage in June, due to the watering of the lawns and fields. This irrigation water is not included in water use for "buildings" in Table 11 or in subsequent domestic water use results.

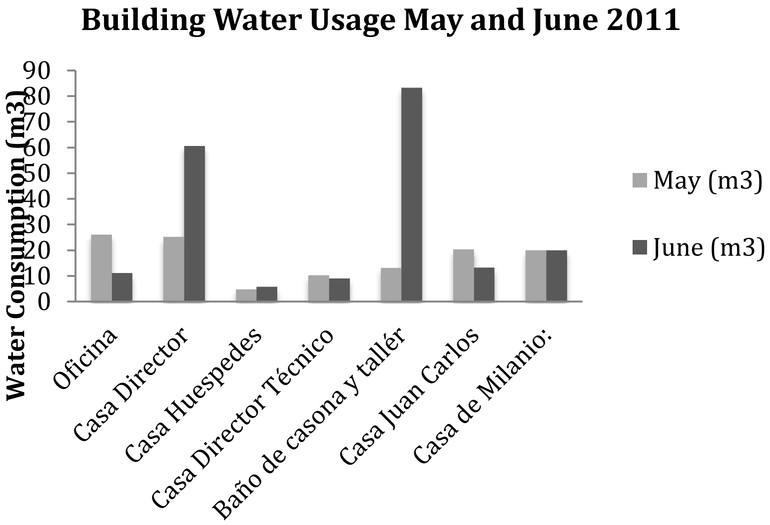

Figure 12.Water usage for specific households, office and an extra bathroom at Ceasip.

A few specific values for collected wastewater for the eastern buildings are stated in Table 12 while a fuller list is given for the specific water flows in Appendix 3.

Table 12. Average collected wastewater flows from the eastern buildings at Ceasip

Eastern buildings	Collected wastewater (liters/day)
1. Office	540
2. House + cafeteria	639
3. House (Casa Huespedes)	160
4. House (Casa Director Técnico)	279
Sum:	**1618**

Based on the gathered data, some generalized average values of water use at Ceasip as well as peak hourly flows are given in Table 13. See Appendix 4 for specific hourly flow graphs.

Table 13. Generalized average water use values at Ceasip

	Water use (liters)		
	Average Per day	Average Per month	Peak Hourly
Farm inhabitant	80	2480	-
Office	610	19000	150
Cafeteria	260	5720	55
Household	387	12000	55

Considering that the average city inhabitant of Santa Cruz uses about 150 l/day, the daily water use of 80 l/day by a farm inhabitant at Ceasip is clearly small by comparison.

Three of the eastern buildings (two households, the office, and the cafeteria) are currently connected to a large, joint septic tank of two chambers with an approximate volume of 8 m^3. The septic tank leads to a soak pit with the volume of about 8 m^3. The other households at Ceasip have their own septic tanks but without infiltration systems.

One of the houses (Casa Juan Carlos) requires the use of a pump to periodically empty the tank while the wastewater from the other households' tanks/pits slowly seeps out into the soil.

The wastewater qualities from *in situ* measurements and laboratory results are presented for the four eastern buildings in Table 14 while the quality results for all the domestic wastewaters are presented in full in Appendix 5.

Table 14.Wastewater quality for the four eastern buildings at Ceasip (Results from UTALAB, Santa Cruz, 2011)

WW source:		**Office, Cafeteria, Casa Director, Casa Huespedes**				**Casa DirTécnico**	
Dates:		**May 24**		**June 24**		**May 24**	**June 24**
Duplicates:		**A1; A2**	**B**	**A**	**B**	**A1; A2**	
Parameter	**Units**						
Temp*	*C	25.2		23.1		27.2	23.4
pH		6.43		6.19		7.7	
Cond*	µS/cm	641		679		1568	1524
DO*	mg/l	6.5				1.4	
Fec Coliforms	MPN/ 100ml	4.30E+06				4.30E+03	
BOD_5	mg/l	262.5	258	350		70	
COD	mg/l			627			
Greases	mg/l	27.2		29.6		10.4	
Total P	mg/l	2.32**	2.82**	2.4**		2.16**	
Total N	mg/l	<5**; 8.1**	3.95E+01	<5**	6.4	135.5; 87.6	<5**
NH_4^+-N	mg/l	38.2		32.5			110.02
TDS	mg/l	371					
TSS	mg/l	64		83		66	
As	ppm	<0.002					
Cd	mg/l	<0.02					
Hg	mg/l	<0.001					
Pb	mg/l	<0.1					

*insitu
** especially unreliable data (see *5.3 Data accuracy)*
Note: A1 and A2 are repetitions of the total N of the same samples

A summary of the quality of all domestic wastewater at Ceasip is presented in Table 15 where results are also compared to legislation limits for discharged wastewater and compared to irrigation guidelines.

Table 15. Quality summary of domestic wastewaters at Ceasip compared to legislation and guidelines

Parameters	Unit	Range	Load ***	Compared to legislation (Table 5)	Compared to irrigation guidelines (Table 1)
Temp*	°C	23.1-28.6	M	✓	✓
pH		6.4-7.7	M	✓	✓
Cond*	µS/cm	387-1568			✓ ■
DO*	mg/l	0.9-6.5			
Fecal Coliform	MPN /100ml	$4.3 \cdot 10^{3}$-$2.5 \cdot 10^{7}$		■	×
BOD_5	mg/l	50-350	L-H	×	
COD	mg/l	~600			
Greases	mg/l	10-30	L	■	
Total P**	mg/l	1.55-2.82	L	×	
Total N**	mg/l	<5-135	L-H	×	✓ ■ ×
NH_4^+-N	mg/l	32.5-110	M-H	×	■ ×
TDS	mg/l	~400	L		✓ ■
TSS	mg/l	64-83	L	■	■
As,Cd,Hg,Pb	ppm, mg/l	Not detected		✓	✓

*measured *in situ*
** especially unreliable data
***compared to typical domestic wastewater. L=low, M=medium and H=high

✓ Acceptable; No restriction on use.
■ Borderline acceptable; Slight or moderate restriction on use.
× Not acceptable; Severe restriction on use.

The raw wastewater should not be discharged untreated since there are many parameters that do not comply with legislation limits. It also becomes apparent that the quality varies significantly between buildings, and that if the raw wastewater were to be used as irrigation water, moderate or severe restriction would be necessary to prevent the overloading of some parameters. High levels of N are extremely valuable from a fertilization point of vew, especially in poor soils like at Ceasip. Nitrogen is mainly needed for plant growth so if applied in excessive quantities when the plants are not receptive, damage or undesirable effects can be caused to the plants or leach out as NO_3^- into groundwater (WHO, 2006). However, considering that the irrigation water flows are significantly larger than the wastewater flows, the diluted wastewater would be acceptable regarding N. More N calculations follow below. The results show severe restriction of use as irrigation water considering the fecal coliform content and the potential health hazards involved. So regardless of the final use or discharge of domestic wastewater, treatment is advisable considering legislation and guidelines.

Quality control of analyses using duplicates showed that both the total N and total P results were unreliable. Despite the unreliable data for total N, the measurement of NH_4^+-N is considered more reliable and since the majority of the N should be in this form, it is a sufficient quantitative indicator of total N. It is likely that the actual P concentrations were higher than what the results showed. However, even if in reality they were not higher, they were too high to comply with legislation for discharge.

The N-flow according to the UTALAB analysis results from different occasions for all the domestic wastewater combined is summarized in Table 16. Averages are shown in the third column for the cases in which two values for the same building existed. The total daily N-flow for all the domestic wastewater is 182823 mg/day, which is equal to 67 kg/year.

Table 16. Potential yearly nutrient flows for domestic wastewaters at Ceasip

Buildings	**N-conc. (mg/l) Lab results**	**Average N conc. (mg/l)**	**WW flow (l/day)**	**N (kg/day)**
Three eastern buildings (1)	38.2	35	540	0.019
Three eastern buildings (2)	32.5			
Casa Director Técnico	110	110	279	0.031
Casa Juan Carlos (1)	107	98	485	0.047
Casa Juan Carlos (2)	88.01			
Total domestic average N conc (mg/l)		**74**		
Applying the average on the following buildings (no data exists):				
"Mid" bathroom			571	0.043
Casa Milanio			581	0.043
Total ALL domestic buildings				**0.18**

According to calculations in *4.3. Nutrient flow calculations,* the implementation of urine separation at Ceasip could lead to the collection of around 78 kg N/year and 8 kg P/year. For the wastewater, using the nutrient flows and the quality results for the three connected eastern buildings and assuming an implementation of urine separation would leave a concentration of around 18 mg/l nitrogen (assuming that only 40% of urine remains and that 87% of wastewater N comes from urine). Compared to the wastewater irrigation guidelines, this would imply only slight or moderate restriction for reuse in agriculture. If the fourth eastern building is connected also, that gives a different concentration (approximately 24 mg/l) because the fourth household had much higher concentration of N, but it still implies only slight or moderate restriction for reuse. Assuming a daily wastewater flow of approximately 1620 l (Table 13) from the four eastern buildings, the nitrogen remaining in the wastewater after potential urine separation are as follows: 1620 l/day·24 mg N/l = 38.8 g N/day or 14.2 kg N/year. During wastewater treatment this nitrogen would undergo some gas losses and some would be converted into biomass. The same calculations cannot be made for phosphorus concentrations due to unreliable data and since a considerable portion of phosphorus content in domestic wastewater originates from detergents and household products.

5.1.2. Dairy factory

Of the water used in the dairy factory, it is assumed that nearly all water is collected as wastewater. Since one outdoor tap provides water for the lawn, that water is excluded from the recollected wastewater amounts. Wastewater is collected and led to a close-by septic tank that is connected to a leach field. A small manhole or access point from the top, which seals well, allows for anaerobic conditions within the septic tank. The average monthly usage of water in the dairy factor is 9 m^3. This is even less than the average usage for a household. The quality of the wastewater, which can be seen in Table 17, is distinctly different from the other wastewaters of Ceasip, having extremely high values of certain parameters.

Table 17. Wastewater quality for the dairy factory at Ceasip (Results from UTALAB, Santa Cruz, 2011)

WW source:		**Dairy factory**	
Dates:		**May 24**	**June 24**
Duplicates:		**A1; A2**	
Parameter	**Units**		
Temp*	*C	27.7	23.5
pH		4.09	3.96
Cond*	µS/cm	6230	8060
DO*	mg/l	0.6	
BOD_5	mg/l	455**	4700
COD	mg/l		19950
Greases	mg/l	11825	2610.8
Total P	mg/l	2.74**	1.5**
Total N	mg/l	2030; 1688	215.6
NH_4^+-N	mg/l		20.9
TSS	mg/l	35778	
Cd	mg/l	<0.02	
Pb	mg/l	<0.1	

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

Note: A1 and A2 are repetitions of the total N of the same samples

What especially distinguishes it are the high concentrations of fat, suspended solids, organic material and nitrogen. Laboratory results obtained by another student confirm this statement. It is certain that such wastewater must be treated further before disposal. Comparing the EPA recommendation of maximum grease content of 30 mg/l in wastewater entering leach fields, to the thousands of mg/l measured in the dairy factory septic tank, it is probable that the leach field from the dairy factory septic tank is clogged and non-functional.

The average of the results for the total N concentrations is 689 mg/l. The volume of collected wastewater is 284 l/day. This gives N flows of 196 g N /day or 71 kg N/year, which is higher than in all the domestic wastewaters combined. Since results for N concentrations vary, more analyses would need to be done to confirm the results.

5.1.3. Stable (calves and milking)

The wastewaters from the milking room and stalls are collected in floor channels that lead outside to a four chamber open septic pit for trapping suspended solids. Every four days, the wastewater is piped out to a field but there is no functional distribution of the water. It quickly infiltrates into the ground and may be one of the contributors to the high fecal coliform concentrations of the groundwater tested in a shallow well some 85 meters south east of the field.

About 45 m^3 of the wastewater from the stable is collected every month in an open septic tank. The quality of the wastewater, shown in Appendix 5, appears to be diluted enough to where only slight or moderate restriction on use is required regarding the nitrogen (NH_4^+-N =17.96 mg/l) and suspended solids concentrations, and no restriction regarding salinity. The fecal coliform content is fairly high at a concentration of nearly 10^7 MPN/100ml.

Using a N-concentration of 18 mg/l gives the following nutrient flow in collected stable wastewater: 18 mg/l·45000 l/month·12 months = 9.7 kg N /year.

Considering that only one sample of this water was analyzed, it is possible that results would vary, but it is regarded an insignificant variation since the routines in the stable are followed closely without much changes throughout the working shifts. As with the domestic wastewaters, despite the unreliable data for total N, the measurement of NH_4^+-N is considered more reliable and since the majority of the N should be in this form, it is a sufficient quantitative indicator of total N.

5.1.4. Animal drinking water

The average drinking water usage (including water that was poured out into the soil) per animal in May was calculated to about 60 liters/day. This is according to assumptions and calculations shown in Appendix 2. However, considering that up to 50% of that water may be poured out, the actual daily water intake per cow may be around 30 liters. Taking into account the large quantities of water constantly provided for the animals and then wasted, there is great potential for developing water-saving habits and projects.

5.1.5. Fruit & vegetable garden, fields

Water flows

The gardens are where the largest portion of on-farm water usage takes place, accounting for approximately 70% of the total groundwater use. Of approximately 600 m^3 used for total irrigation per month, about 70-95% was used in the fruit and vegetable gardens (an average of May and June gives 490 m^3/month) while the rest of the irrigation water included in the study was used for lawns and fields.

These results would certainly vary for different seasons. During the months prior to May and June, more precipitation reduces the need for constant irrigation. Even so, a garden employee estimated that watering was practiced on average a couple times per week during the wetter season. The reduced watering leads to a weekly usage of 38 m^3, which would give an irrigation flow of approximately 152 m^3/month during the wetter months.

If the collectable wastewater produced from the four eastern buildings were to be recycled as irrigation water in the gardens, the combined wastewater amounts to 51 m^3/month. This would mean that about 10% of the need for irrigation water in the gardens could be covered by reused wastewater during the dry season and about 33% during the wet season. This would entail a considerable reduction of groundwater usage.

Nutrients/fertilizer

The crop needs for fertilizer is shown in Table 18. If the nutrients in humane urine from the whole farm were to be reused in agriculture, this would result in the areas in Table 19 being potentially fertilizable by urine. The areas range between 0.7-4.4 ha for a few different crops. This can be compared to the fertilizing recommendations in *Informe Técnico* (Ceasip, 2009). The recommended amount of nonorganic fertilizers at Ceasip for *Sorghum Massa* was 100 kg/ha of Triple 15 fertilizer, which would provide 15 kg/ha of N and P respectively (Ceasip, 2009). If following the N-recommendation with the available urine nutrients, this would allow urine to fertilize 78.1/15 = 5.2 ha whereas the P-demand would allow only 8.5/15 = 0.57 ha to be fertilized. However, considering that the recommendation for Ceasip was to combine nonorganic with organic fertilizers, this only compares to the nonorganic portion of the actual fertilizing recommendation of the area being cultivated.

Table 18. Amounts of N and P (kg/ha) removed per metric ton of harvested edible fraction for different crops. All grain yields are considered dry.

Crop type	N removed per ton** (kg/ha)	P removed per ton** (kg/ha)	Yield (tons/ha)	Crop need N (kg/ha)	Crop need P (kg/ha)
Maize (Ceasip)	15.1	2.1	2.5*	37.75	5.25
Maize (Bolivia, FAO, 2009)	15.1	2.1	2.8***	42.28	5.88
Sorghum (Ceasip)	17.6	2.9	4.15*	73.04	12.04
Sorgum (Bolivia, FAO, 2009)	17.6	2.9	3.3***	58.08	9.57
Tomato (Bolivia, FA0, 2009)	1.4	0.3	12.8***	17.92	3.84

*According to Informe Técnico 2007-2009
**According to Jönsson et al. 2004
***national average yield for Bolivia

The results in Table 19 are calculated according to the crop need in Table 18 and the available urine nutrients.

Table 19. Areas that are potentially fertilizable by collected urine at Ceasip

Urine nutrients from Ceasip (kg/yr)		Areas (ha)				
		Maize (Ceasip)	Maize (FAO)	Sorghum (Ceasip)	Sorghum (FAO)	Tomato (FAO)
N	78.1	2.1	1.8	1.3	1.3	4.4
P	8.5	1.6	1.4	0.7	0.9	2.2

While Ceasip yields vary in different experiments and years, the data from *Informe técnico 2007-2009* (Fundación Simon I. Patiño, 2009) for the dry grain yield for maize and sorghum were used. Since data of average yields during other years was not available, the numbers should be understood as approximate. National average yields (according to FAO) are only shown to give the reader some perspective, since there is a wide variety of physical conditions in Bolivia. Other uncertainties also exist regarding how much urine could be collected and how much nutrients are in the urine. The areas potentially fertilizable by urine are larger for N than P.

5.1.6. Groundwater, distribution net and water receptors

From measurements made in old wells no longer in use, the ground water table during May was at a depth of about 6-7 m. It was most likely deeper down during the drought months of this study, compared to other parts of the year.

The water quality from a laboratory analysis of the shallow well is shown in Table 20. Several "out of the ordinary" qualities can be noted. First of all, the coliform content of nearly 10^6 MPN/100ml which is almost as high as for domestic and stable wastewaters. Since both fecal and total coliform bacterial concentrations were tested, and the result was exactly the same, this means that practically all of the coliform contamination must be fecal. The source of the bacteria may be the paddock around the stable since it is likely "uphill" in the underground water currents from where the sample was taken as well as a number of other possible sources.

Other qualities worth noting are the high electrical conductivity/salinity of over 850 µS/cm and a Pb concentration of 0.2 mg/l. High salinity in the groundwater could be an indication that the salts get flushed or leached out from the upper soils. Lead concentration exceeds the drinking water limits of 0.01mg/l (cf. to Table 6). However, the salinity may be only slightly restricting and the Pb concentration does not exceed recommended limits for reuse as irrigation water (cf. to Table 1)

The tap water quality is also presented in Table 20. It showed normal pH, low alkalinity (=soft), a safe concentration of 2.8mg/l NO_3^- (far below the WHO maximum recommended limit for drinking water of 50 mg/l), moderate concentrations of Fe, very low salinity and dissolved solids, and slight coliform content. However, there were no detected fecal coliforms. The microbial analysis of the sample taken directly from the deep drilled well showed an even lesser concentration of total coliforms. This could mean that the storage tank and distribution net could have some bacterial growth. Since no fecal coliform are present, and other values are very good, this implies that the deeper groundwater is still much purer than the groundwater close to the surface. However, the high contamination of the shallow ground water is worrying, as this risks spreading downward.

Table 20. Water quality of ground waters at Ceasip (Results from UTALAB, Santa Cruz, 2011)

W source:		Tap water (Casa Huesp.)		New deep well (direct)	Old shallow well
Dates:		May 24	July 2	May 24	May 24
Duplicates:					
Parameter	Units				
Temp*	*C	26.6	16.6		24.9
pH		7.76	7.7*		7.29
Cond*	µS/cm	70.3	68.6		851
DO*	mg/l	6	7.3		2.9
Alcalinity (CaCO3)	mg/l	34			
Fec coliform	NMP/100ml	<2.00E+00		<2.00E+00	9.30E+05
Tot Coliform	NMP/100ml	2.70E+01		2.00E+00	9.30E+05
Total P	mg/l				0.51**
NH_4^+-N	mg/l				<0.02
NO_3^-	mg/l	2.8			
TDS	mg/l	81			
Total Fe	mg/l	0.33			
Manganese	mg/l	<0.02			
As	ppm				<0.002
Cd	mg/l				<0.02
Pb	mg/l				0.2

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

*** after rainy days, approx 34 mm in 3 days

Note: A1 and A2 are repetitions of the total N of the same samples

Of the two lagoons observed on the property, with quality results presented in Appendix 5, the southwest lagoon closer to the workshop showed more signs of contamination. Fecal coliform concentration and salinity were higher. This could be an indication that runoff water from the stable area or household wastewater leachate reaches the lagoon. The other lagoon, on the northeast side, has a much larger area and contained very little water during the field study.

5.1.7. Summary of nitrogen-flows

The yearly N-flows from the buildings, the dairy factory and the stable formerly described are summarized by Figure 13.

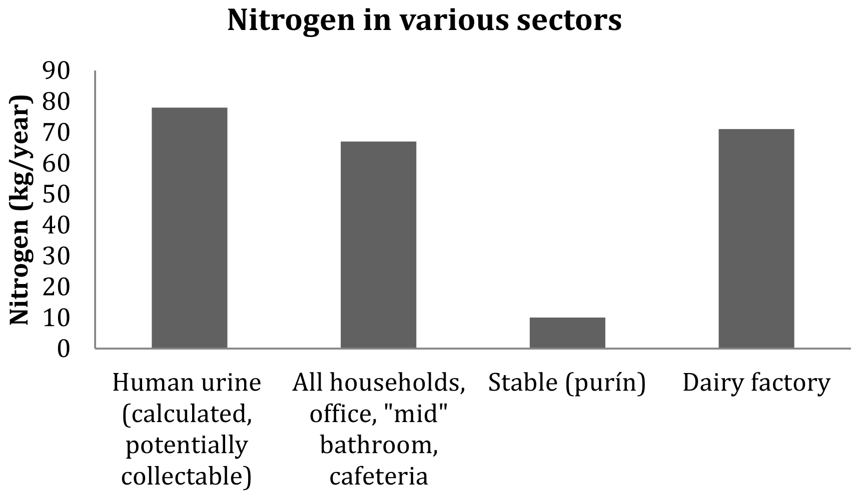

Figure 13. Overview of yearly nitrogen flows in human urine and in the wastewater from different sectors at Ceasip, assuming 65% of the urine is source separated and collected.

Comparing the calculated nitrogen potentially collectable from human urine, this differs from the total nitrogen in wastewater from households, office, etc. It was expected that the human urine calculations show less total nitrogen than wastewater. The differences may be explained by nitrogen losses in gas, misleading water quality results from the laboratory and/or overestimation of nitrogen in urine. They are however in the same range, which proves that the calculations and quality results are reasonable. Somewhat unexpected was also that the results show that dairy factory wastewater is a big contributor to total nitrogen flows at Ceasip while the stable wastewater is a relatively small contributor. In other words, this suggests that theory is consistent with reality.

5.2. PHYSICAL CONDITIONS

Many of the physical conditions have already been described in "Site description" and the former section.

Hydraulic conductivity (K) from percolation tests in three different points in the areas where treatment was deemed appropriate for the combined eastern buildings, are shown in Table 21.

Table 21. Hydraulic conductivity of several points at Ceasip from percolation test results

	Location	Depth of pit (cm)	K (cm/s)	K (cm/min)	Infiltration time (min/cm)
1	By large soak pit	49	$6.20\cdot10^{-4}$	0.037	27
2	By northeast lagoon	56.5	$2.60\cdot10^{-4}$	0.0158	63
3	Between lagoon and soak pit	60	$6.35\cdot10^{-5}$	0.00381	262

These low hydraulic conductivities are somewhat surprising compared to the expected values from the soil texture mentioned earlier for the western wing, according to the report by Agroconsult, 2006. From the report it was clear that in the soils around the buildings, the sand content was as high as 80% while the silt and clay content were about 10% respectively. If it were as such, then K would have been closer to 10^{-3} cm/s, so the soil is more clayey than expected.

These results indicate that conditions are less suitable for treatment/disposal systems like leach fields because according to the US EPA (2000), the soil is not suitable if the infiltration time is over 47 min/cm. The results give an average of 118 min/cm while two out of three points are unsuitable. However, because of the variability and patchyness of the soils, undoubtedly there must be other locations than the ones tested which are more suitable, with soils like the Agroconsult report states. Using report values instead, assuming zone A in Figure 24 (section *6.6.4. Leach fields*) would give a possible wastewater hydraulic loading rate of 40 l/m^2&day. For a typical household water usage, and assuming that 90% of water used is collected as wastewater (which seems reasonable according to observations), that would give a minimum leaching field area of 9 m^2 per household. (387 l/day·90% /40 l/m^2&day = 8.7m^2) But actual dimensions would need to be bigger to allow for visitors etc. With some leeway, 500 l/household&day gives an area of 12.5 m^2. To find an area of this size of suitable soil may be difficult considering the soil patchyness.

5.3. DATA ACCURACY

The water flow data are of varying accuracy. While the data recorded from the water meters falls within an accuracy of 5% more or less than values shown, the other estimated and calculated water flows where no water meters were installed may be less accurate.

For quality assurance of laboratory analyses, the supposed P-concentration was "known" to me and not to the lab. It was however not a 100% assurance since the concentration was prepared by the same UTALAB, which I subsequently diluted using distilled water and by weighing on a scale before turning in it again at a different concentration. There may have been errors made in the lab in the initial making of the P-concentration, or an error may have been done by my part also, despite careful calculation, measurements and mixing. Otherwise the error may have occurred in the analysis of the actual samples.

Total N results from laboratory analyses proved to be unreliable since duplicates did not match and NH_4^+ concentrations were higher than total N. According to the analyses, NH_4^+ was assumed to be a sufficient indicator of N in domestic wastewaters. However, this means that other N forms are not included and that in reality, total N concentrations are marginally higher.

While the BOD_5 values from most of the results were acceptable (considering that duplicate values were similar), the dairy factory results for May 24 seemed extraordinarily low. It was probable that a dilution factor of 10 was missed in the calculations at the laboratory.

Although the high Pb value in the shallow well water suggests that the groundwater is contaminated, it is impossible to say from the result to what extent since the Pb value was only measured one time in one point. The possibility exists that the high value could be due to a point contamination from trash in the surroundings, such as batteries or leaded petroleum, or that errors in the laboratory analyses were made.

6. REVIEW OF RELEVANT TECHNOLOGIES

A screening of wastewater technologies was done to find the most relevant systems and technologies considering feasibility. Also a description of the parts of the current system at Ceasip is included in this section. Different approaches to relevant systems and suitable technology are reviewed. No specific evaluation of sustainability criteria is done in this section. The input and output products (listed below) of different parts of the systems are considered and the system functions will be described in functional groups, which are adopted and somewhat simplified from the *Compendium of Sanitation Systems and Technologies* (Tilley et al., 2008) and defined accordingly.

Input/output products:

- Urine - see former section.
- Feces - see former section.
- Toilet paper – dry cleansing material.
- Drying materials - i.e. ash, lime.
- Flush water - In most cases, potable water is used in quantities up to 10 l per flush.
- Fecal water - Feces plus flush water.
- Graywater - see former section.

Functional groups:

- User interface – describes the type of toilet or urinal in which the users access the sanitation system. Although graywater does not enter the system at the same point as other input products, it may still be treated along with the user interface-products.
- Collection and storage/treatment – describes ways in which to collect, store and sometimes treat the user interface input products.
- Conveyance – describes the means of transport between functional groups. For simplicity's sake it is limited here to the transport between storage and treatment.
- Onsite treatment – describes treatment technologies that are appropriate for multiple households.
- Use and/disposal – refers to methods in which the products are either recycled in the system, used outside the system or returned to the environment,

6.1. DIFFERENT MANAGEMENT APPROACHES

In this study, three main management approaches to classify the possible solutions are defined and considered. Despite the differences, all systems have certain functions and products in common. The three considered system approaches are named *Dry source separation*, *Wet source separation* and *Mixed wastewater*. Descriptions of each approach are given, followed by the technology review where it is noted what technology is suitable for each approach.

6.1.1. Dry source separation

Dry source separation of urine and feces, graywater separate:

Both urine and feces are separated at the source without the use of flush water while graywater is kept separate. Different treatments are used on each waste type. The treatment of graywater is separate for which the system may include any of the treatments mentioned further on. This approach creates smaller volumes that are easier to treat than in the other approaches. Suitable fertilizer products are created. Some restrictions are required in handling. See Figure 14 for an overview of the possibilities for this approach.

To achieve Dry source separation, an *eco-toilet* is required (see description below). There are two eco-toilet options, indoors and outdoors. For an eco-toilet to be installed indoors requires higher technical solutions in order to prevent problems with smells and flies whereas a separate toilet building outside allows the functional groups to be technically more simple and robust. For an indoor eco-toilet, an electrically run fan should be on at all times to suck the smells out of the feces collection chamber while separate toilet buildings outdoors only require a ventilation pipe from the feces chamber where a suction is created from the wind. Thus considering the social sustainability criteria[1] and due to unreliability of constant electricity supply at Ceasip, only the outdoor eco-toilet will be reviewed.

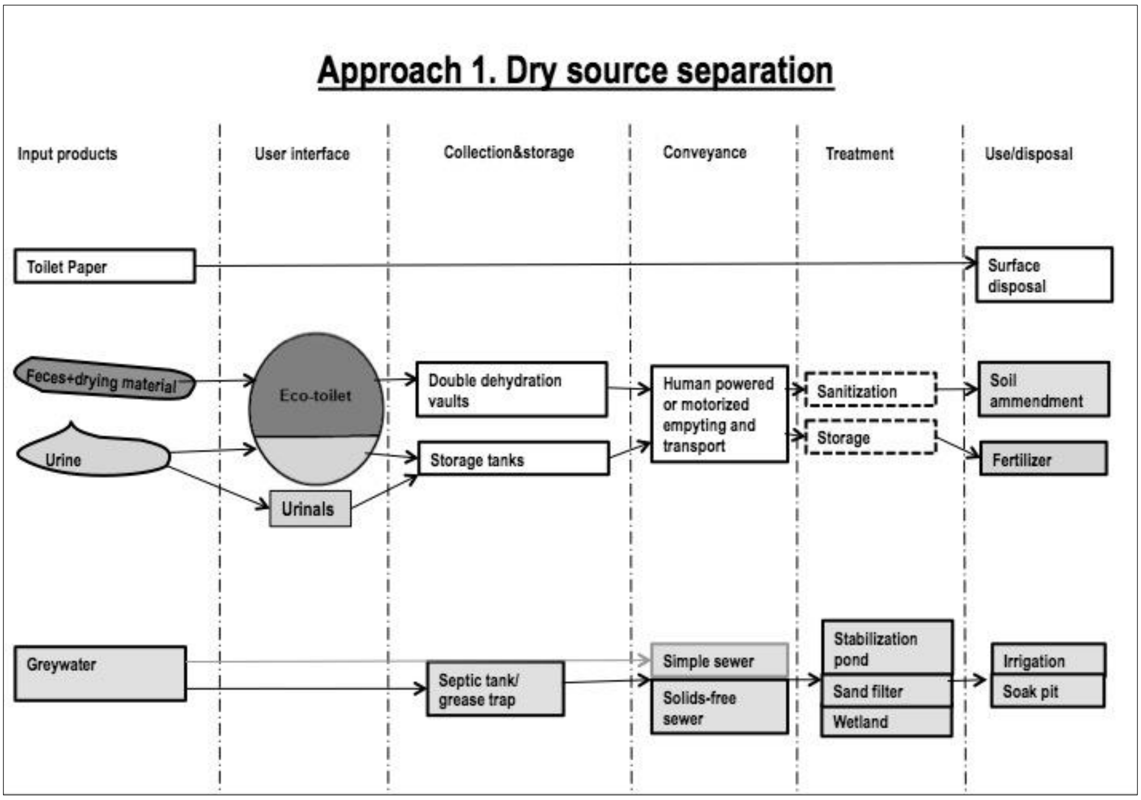

Figure 14. Schematic sketch of the dry source separation approach (Author's figure inspired by Tilley et al. (2008)).

6.1.2. Wet source separation

Urine separation with water flush toilets:

[1] Bad odors and acceptance

Urine is separated at the source from the rest of the wastewater and treated separately. Feces and graywater, however, are treated together. While this approach produces large volumes of “hazardous” waste that require extensive treatment, it also creates a suitable fertilizer product in the form of urine. There is a greater risk of downstream pollution compared to Dry source separation due to fecal water. Wastewater and sludge are also possible recycling products. See Figure 15 for an overview of technological possibilities within this approach.

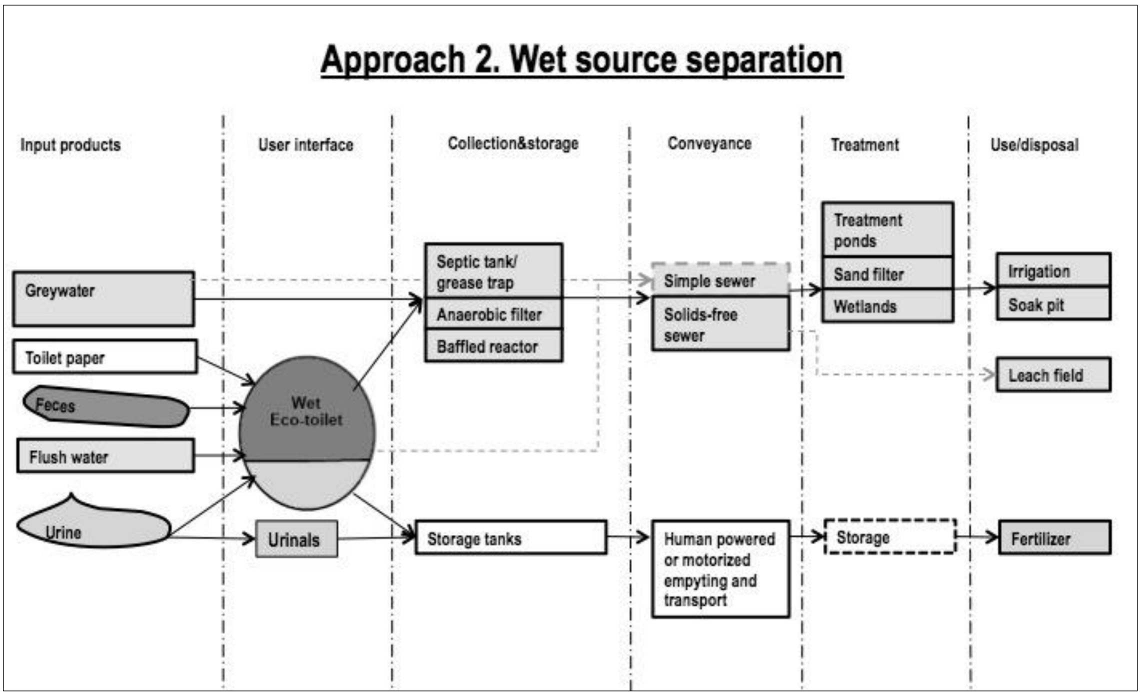

Figure 15. Schematic sketch of the wet source separation approach (Author’s figure inspired by Tilley et al. (2008)).

6.1.3. Mixed wastewater

Feces, urine and graywater are all discharged and treated together. Conventionally, this is the most common approach and this is the current approach at Ceasip. This approach produces large volumes of “hazardous” waste that require extensive treatment. There is a greater risk of downstream pollution. Possible recycling products are wastewater and sludge. See Figure 16 for an overview of some possibilities within this approach.

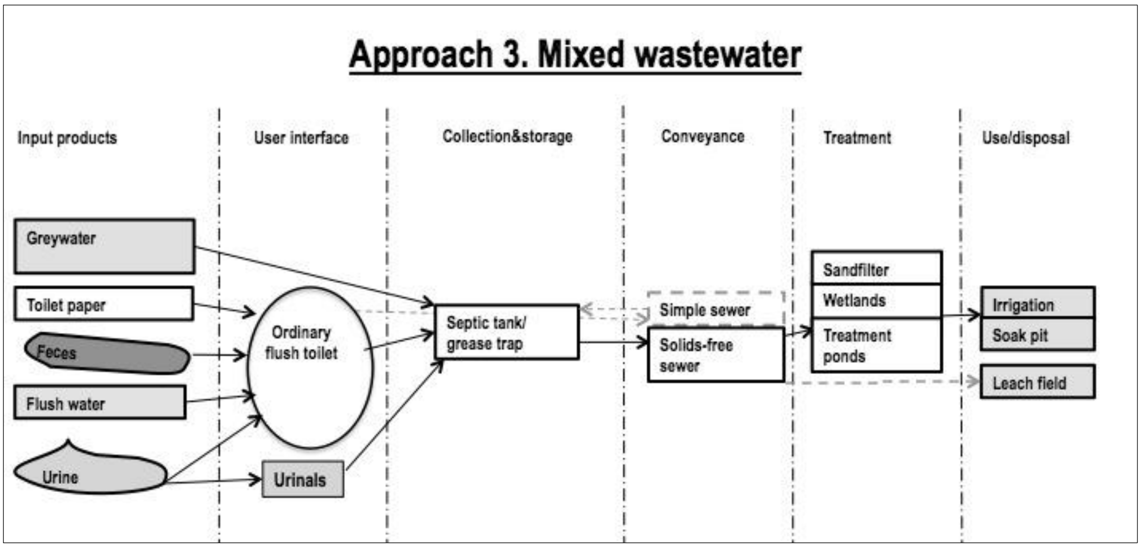

Figure 16. Schematic sketch of the mixed wastewater approach (Author's figure inspired by Tilley et al. (2008)).

6.2. USER INTERFACE

A few feasible options for the user interface are described in this section.

6.2.1. Eco-toilet

(Suitability: Dry source separation)

Dry source separation of urine and feces can be achieved using what is known as a *Urine Diverting Dry Toilet* but will for simplicity's sake be mentioned here as an *eco-toilet*. The basic design, as shown in Figure 17 is a toilet bowl with a divider that allows the urine to be diverted from the feces without imposing much effort upon the user. The urine is drained from the front of the toilet bowl while the feces fall through a hole/chute in the back; they are collected into separate storage containers of choice. Input and output products are urine, feces and drying materials. Depending on the subsequent treatment of feces, like dehydration vs composting, it may be preferable for toilet paper to be disposed of separately[1]. The eco-toilet can be built from locally available materials such as cement, plastic or be made out of porcelain. Maintenance/upkeep can be slightly more difficult than other toilets since large quantities of water should not be used for cleaning and there can be a build-up of salts from urine in the pipes. (Tilley et al., 2008)

[1] Another view is that the toilet paper should be added to feces regularly regardless of whether deyhration or composting is the subsequent treatment. (Jönnson, (pers. comm), 2011)

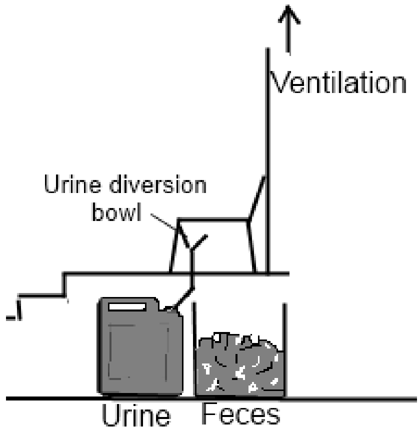

Figure 17. Eco-toilet. Urine is collected from the front of the toilet while feces are collected from the back.

6.2.2. Urinal

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

Urinals are user interfaces that only collect urine. They are applicable for all the approaches mentioned. A wide range of styles and complexities exist and although urinals are typically used by men, special urinals for women have also been developed. Urinals can be designed with input products as urine only or as urine plus flush water. Large amounts of urine can be either collected or discharged. To prevent odors, a water-seal or other type of seal can be used. Correct cleaning and maintenance prevents build-up of salts in pipes and bowl. (Tilley et al., 2008) Some urinals are currently installed at Ceasip.

6.2.3. Ordinary flush toilet

(Suitability: Mixed wastewater)

The *ordinary flush toilet*, otherwise known as a *cistern flush toilet*, is an ordinary toilet pedestal (usually in porcelain) with a water tank (or cistern) to supply flush water. Excreta inputs and in many cases toilet paper are flushed away together to the subsequent storage or conveyance technology. A water seal that enters the toilet bowl prevents odors. Maintenance and cleaning is required to keep toilet stain-free. (Tilley et al., 2008) This is the current user interface at Ceasip.

6.2.4. Wet eco-toilet

(Suitability: Wet source separation)

Wet source separation of urine and feces can be achieved using what is known as a *Urine Diverting Flush Toilet* but will for simplicity's sake be mentioned here as a *wet eco-toilet*. The wet eco-toilet is a combination of an eco-toilet and an ordinary flush toilet. Typically it is a porcelain pedestal with a divider to separate urine from feces. Urine collects in bowl in the front while feces fall into a water filled bowl in the back. Inputs of urine and feces (possibly combined with toilet paper) are then flushed separately to storage or treatment, which requires dual plumbing and is somewhat more complicated than the plumbing for an ordinary flush toilet. Maintenance and cleaning is required to keep toilet stain-free and to prevent clogging of urine pipes. (Tilley et al., 2008)

6.3. COLLECTION AND STORAGE/TREATMENT

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

Different options to collect and store the products from the user interface are given here. Storage may provide certain treatment depending on the storage/retention time. In approaches two and three it is necessary to provide a certain amount of treatment before wastewater enters the main onsite treatment.

6.3.1. Urine storage tanks/containers

(Suitability: Dry source separation, Wet source separation)

Tanks or containers can be used to store urine from the eco-toilet and the wet eco-toilet user interfaces, appropriate for the first and second approaches. The size of the tank or container depends on the number of users and the desired storage time. If a large immobile tank is chosen as a holding tank (i.e. Figure 19), it must be equipped with a pump (otherwise allow for access from a vacuum truck) to remove the urine for transportation. Pipes leading from the user interface to holding/storage of urine should be steep (greater than 1%), have large diameters (up to 110 mm), have no sharp angles and be easy to flush/cleanse in case of blockages. Pipes should lead urine close to bottom of the tank to prevent gas flow. Tanks should be made out of non-corrosive material like plastic or concrete since urine can otherwise be damaging. *Jerrycans* are light plastic containers of approximately 20 l with handles (Figure 18) that are easily transportable. They may be stored with lids as are, or emptied into a larger storage container/tank for storage. (Tilley et al., 2008) If jerrycans are used, plastic should be black, as it is more resistant if left in the sun; if holding tanks are used, concrete is the preferred material as it is fairly resistant and is a better option considering energy requirements for production and local labor possibilities (Hylander, 2011).

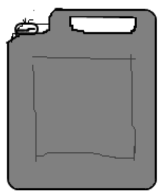

Figure 18. Jerrycan.

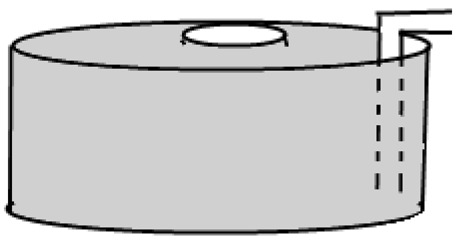

Figure 19. Urine holding tank.

Storage of urine in well-sealed, airtight tanks or containers is an effective way of sanitizing the product from potential pathogens due to the naturally occurring compound of urea that forms a part of urine. Urea breaks down rapidly to ammonia, causing an inactivation of pathogens. The longer the product is stored (also depending on temperature) the safer it becomes, but typically “pure urine” should be stored for at least one month. If urine is potentially cross-contaminated like from an eco-toilet or wet eco-toilet, a longer storage period is advisable. A storage time of over 12 months, may also help reduce odors of the product (Jönnson, (pers. comm), 2011). A build-up of sludge during storage at the bottom of the tank or container is normal due to precipitation of salts and sedimentation of organic material. (Tilley et al., 2008)

6.3.2. Dehydration vaults

(Suitability: Dry source separation)

In Bolivia, a well-tried and technically feasible option to combine with the eco-toilet user interface is *dehydration vaults.* These consist of two vaults, in a base built of concrete or sealed block, which are used alternately to collect, to store and to dry feces. Urine is diverted away from vaults. Vaults should be waterproof to prevent outside moisture from entering and be equipped with a ventilation pipe and fly screen to help dry the feces, minimize smells and control flies. After an input of feces has been made, it should be covered with drying material such as ash, lime or soil. Since fees are dried and not degraded, it is best to dispose of cleansing material like toilet paper serparately[1]. When one vault is full, leaving some space for airflow, the eco-toilet interface is moved to the other vault. Feces are then let to dry for at least six months before removal. The end product is dehydrated feces, which are then a crumbly, white-beige, coarse, flaky material or powder with a volume of about 25% compared to the wet feces. Vaults should be easily accessed to allow for emptying. (Tilley et al., 2008)

6.3.3. Anaerobic reactors

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

An anaerobic reactor is a chamber (or body of water) designed to anaerobically digest the organic material in wastewater without the presence of oxygen. Anaerobic reactors are suitable for storage/treatment of mixed wastewater in the third approach, or for graywater in approaches one and two. Common for all anaerobic reactors is the need for desludging. The frequency of the necessary desludging depends on the dimensions of the reactor in relation to the load, and the temperature. They should be checked yearly although it may be enough to empty or unclog them every 2-5 years. If they are not maintained and excessive sludge builds up, sludge escape can be the result and harm the subsequent parts of the system. (Tilley et al., 2008) A few simple, “low-tech” anaerobic reactors are described in this section.

Septic tanks

Septic tanks are chambers meant for the storage and partial treatment of wastewater. They can be made of concrete, fiberglass, PVC or plastic and must be watertight. Septic tanks fulfill an important role in most decentralized wastewater treatment systems. Their primary functions are to reduce solids so as to avoid the overloading or clogging of subsequent conveyance and treatment. This is achieved by the sedimentation of the heavy particles and flotation of light particles. Some separation of nutrients is achieved, as some nutrients are bound to particles. Separation of P and N is normally around 10 – 15% (Svenskt Vatten, 2010). Depending on the climate and the *hydraulic retention time* (HRT), BOD can also be reduced considerably. In warmer climates, the degradation of BOD in septic tanks is much higher than in cooler climates. They should

[1] This is not judged to be necessary according to Jönsson (2011, pers. comm.).

have at least two chambers separated by a baffle to allow for separation of scum (greases) by floatation up and the solids by settling before water is discharged. In a well-designed septic tank, with a sufficient hydraulic retention time (HRT) and well-placed baffles, the removal of solids generally amounts to at least 50%, BOD is reduced 30-50% and approximately 1-log reduction of *E.coli* is obtained. (Tilley et al., 2008) The recommended HRT varies from as little as 8 hours (Ridderstolpe, 2007) to 48 hours (Sasse, 1998), largely depending on which dimensioning flow it is calculated from. The Ceasip farm currently uses a combined septic tank for three of the eastern buildings while the other wastewater sources have individual systems (a few of which have septic tanks).

Grease and grit traps

Grease and grit traps are chambers similar to septic tanks; however, when a grease trap is built separately from the septic tank, the HRT only needs to be long enough to allow water to cool and for grease to float up and for the heaviest grit to sink down, but not allowing sufficient time for all solids to settle as the HRT can be as low as a few minutes up to a half hour. This means that the dimensions do not need to be as large as for a septic tank. They are intended to trap grease at an early stage in the treatment system so as to prevent the clogging of the system. They are only necessary as a separate part before entering septic tank when grease concentrations are especially high, like from restaurants. A few characteristics are summarized here.

- Advantages: smaller and cheaper than septic tank, efficient grease removal
- Disadvantages: low TSS and BOD removal efficiency; requires frequent maintenance; odor nuisance if not sealed; unpleasant cleaning
  (Morel & Diener, 2006)

Baffled reactors

Baffled reactors are improved septic tanks suitable for toilet wastewater, forcing wastewater to flow over and under a series of baffles before discharge; thus a higher-rate anaerobic system is achieved due to intensive contact between active biomass and substrates. Although they are suitable for all kinds of wastewater, they are especially appropriate when there is a high percentage of non-settleable suspended solids and a narrow COD/BOD ratio (Sasse, 1998). Instead of the typical 30-50% BOD removal in septic tanks, baffled reactors can effectively remove up to 90% of BOD. The reactor should be designed to have a HRT between 48 and 72 hours, an up-flow velocity of less than 0.6 m/h (Morel & Diener (2006), states v_{max} of 1.4-2 m/h) with 2 to 3 up-flow chambers. The tank should also be vented to provide for gas release. (Tilley et al., 2008) According to Morel & Diener (2006) it also has a sedimentation chamber. A few characteristics are summarized here.

- Advantages: high treatment performance, high resilience to hydraulic and organic shock loading, long biomass retention times, low sludge yields.
  Disadvantages: more expensive than a conventional septic tank, clear guidelines are not available, construction and maintenance are more complex than for conventional septic tanks, emits methane to atmosphere
  (Morel & Diener, 2006)

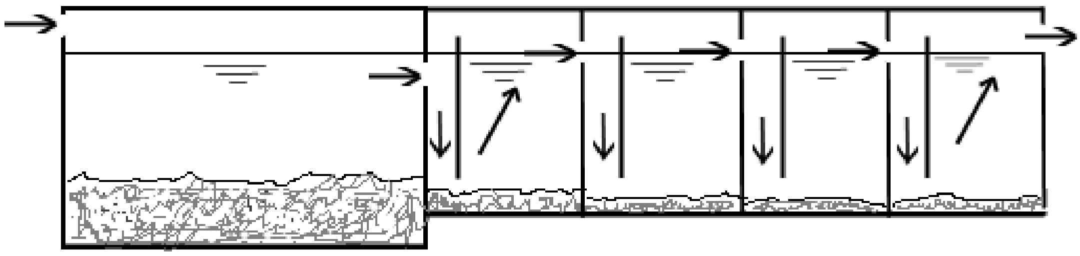

Figure 20. Baffled reactor (Author's figure, inspired by Sasse (1998)).

Anaerobic filters

Anaerobic filters are high-rate systems that use a filter media to provide good contact between the biomass and substrates. They are suitable for wastewater with low percentage of suspended solids (i.e. after solids settlement in septic tank) and a narrow COD/BOD ratio (Sasse, 1998). Filter media may be anything non-degradable that provides a surface area for biomass to grow on in the size range of 12 to 55 mm diameter, i.e. gravel, crushed rocks, cinder, or specially formed plastic pieces. An upflow design is better in securing that biomass will not be washed out. A HRT of 12 to 36 hours is typical. Reduction of BOD is normally around 50 to 80% although it can be as high as 90%. Filter efficiency improves after a long start up time, but also decreases as the filter accumulates too much biomass and particles. Maintenance and cleaning of filter media should then be done, either by reversing flow through filter or removing media. (Tilley et al., 2008)

6.4. CONVEYANCE

In this section the *conveyance* or transport of the products previously collected or stored, is described with various feasible alternatives.

6.4.1. Emptying and transport

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

Conveyance of products can be achieved through human powered or motorized emptying and transport. This involves different activities. Safety measures should be taken for the protection of the workers to avoid body contact with sludge or other products by wearing gloves, boots, overalls and in some situations facemasks. In the dry or wet source separation approaches, humans can easily carry urine in Jerrycans. If a storage tank has been used, then a manual or motorized pump needs to be used to first pump urine into more manageable containers before transport to the area of continued storage or use. Otherwise a vacuum truck can be used if available to empty and transport urine. In the dry source separation approach, dried feces should be shoveled out from the vaults and transported in something manageable (i.e. containers, barrels or carts) to the area of continued storage/treatment or use. In the case of anaerobic reactors like in the mixed wastewater approach, accumulated sludge can be pumped either manually or with a vacuum truck. (Tilley et al., 2008)

6.4.2. Sewer systems

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

Although in cities and larger communities, sewer systems can lead wastewater to a centralized treatment off-site or be discharged into water receptors without treatment, in the case of this study, sewers are only on the Ceasip property and lead wastewater to an onsite treatment. Sewers are appropriate for toilet wastewater in approach three, and for graywater and fecal water in approaches one and two.

Simple sewers can lead wastewater away from households at shallow depths using gravity. A simple sewer system is dependent upon sufficient water flow and velocity to achieve self-cleansing transport. Simple sewers should have interceptor tanks and grease traps for each household before the water is discharged into the sewer. Inspection chambers should also be set out at connections and at certain intervals to ensure access for maintenance and removal of blockages. (Tilley et al., 2008) Due to the shallow depth of the sewer, pipes are also more vulnerable to damage from impacts from above, such as heavy vehicles driving over them. This is the current conveyance system at Ceasip, but without interceptor tanks or grease traps.

Solids-free sewers are an improved simple sewer since they make use of an anaerobic reactor such as a septic tank for each household before the wastewater is discharged into the network. Since wastewaters are then solids-free, a lesser gradient and velocity is required for self-cleansing transport and fewer inspection points are necessary. Both full and partially filled flows are appropriate, which means that little water is required to keep the system in good condition. However, septic tanks require regular desludging. (Tilley et al., 2008)

6.5. ONSITE TREATMENT

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

Finally a few treatment technology alternatives that are suitable for onsite treatment of toilet wastewater, fecal water and/or graywater are described. Because of the varying characteristics of wastewater, to effectively treat different types of contamination, various treatment techniques (including anaerobic and aerobic processes) may need to be applied. However, these treatments need to be adapted for the intended disposal or reuse of the water. The following treatments require pre-treatment according to the previously described storage/treatment. The pre-settling of solids and removal of excessive grease is critical.[1]

Conventional activated sludge systems will not be considered or discussed since these systems require large quantities of energy, complex operation and maintenance (Mara, 2004), and are not appropriate for such small-scale treatment like the Ceasip. Upflow anaerobic sludge blanket reactors are also disregarded as an option considering the small domestic wastewater flows on the farm compared to the high investment costs required compared to other alternatives. The main advantage would be to save space (Mara, 2004), which is not currently the most important issue on the farm.

6.5.1. Sand filter

Wastewater treatment through sand filters is based mainly on aerobic processes. Sand filters can be constructed for either vertical flow or horizontal flow. Vertical sand flow

[1] i.e.max ca 30 mg/l grease in effluents to leach fields (US EPA, 2000)

filters can be more efficient but require higher technology and more maintenance, which is why they will not be discussed further as an option.

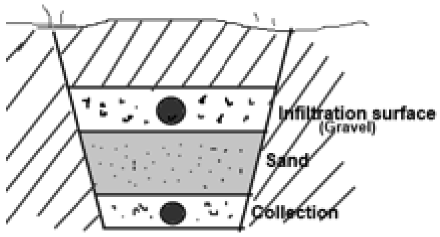

Figure 21. Cross-section of horizontal sand filter (Author's figure inspired from Naturvårdsverket, 2003).

A horizontal sand filter as shown in Figure 21 is based on the same principles as a leach field (see *6.6.4. Leach field*). The difference is that a sand filter effluent is collected after the filter rather than infiltrating into the soil. This can be achieved by laying an impermeable material under the filter along with perforated collection pipes at the bottom of the filter. This allows for control of the effluent before it is discharged, but it also limits the amount of filtering material available for the treatment process. Similarly, a sand filter can be designed to reinforce the capacity to treat hydraulic and biological loads.

6.5.2. Wetlands

Wetlands, which can exist naturally or be constructed, are systems that take advantage of natural processes to clean water. Natural wetlands have surface flow, while constructed wetlands can be either with a surface flow or subsurface flow. Subsurface flow wetlands have a faster BOD removal than surface flow wetlands (up to 5 times faster). (Kadlec & Knight, 1996) Therefore, a description of subsurface flow wetlands is prioritized in this section. Constructed wetlands are suitable for wastewater with low percentage suspended solids and with COD concentrations below 500 mg/l (Sasse, 1998).

Vegetated submerged wetland

Vegetated subsurface vertical flow wetlands are constructed wetlands and are similar to sand filters, except with submerged plants. They can be constructed so that water flows into a medium of rock, gravel, sand and/or soil. Suitable plants aid treatment as well as benefit from the water and nutrients.

Various treatment mechanisms (including aerobic, anoxic and anaerobic processes) take place in wetlands. The organic load can be efficiently treated, nutrients can be removed biologically and through the uptake of plants and animals, while heavy metals and other contaminants can be removed from the water through accumulation in the system. P removal requires the large area compared to other parameters. There is some removal both through bioprocesses and through physical processes. Bioprocesses are not efficient in the long term since plants and animals take up nutrients but then decompose, unless removed from system by harvesting (which is time consuming and tedious). Depending on subsequent use or disposal, additional treatment may be needed. (Tilley et al., 2008)

In order for the plants to contribute to the water purification, certain requirements need to be met. There should be sufficient incident light, an adequate temperature and adequate quantities of nutrients. Furthermore, the wastewater should not be too toxic, should have a long enough detention time in the system (HRT is usually 3-7 days), enough space and not too high organic loading. To achieve a reduction of nitrogen, extensive pretreatment or large wetland area (5 ha/1000m^3/d) is required. (Kadlec & Knight, 1996) A few characteristics are summarized here.

- Advantages: Efficient removal of organic matter, no wastewater above ground level; no odor, mosquitoes or contact to users, cheap to construct where filter material is available locally, pleasant landscaping and possible to use harvested biomass
- Disadvantages: High permanent space and extensive construction knowledge and experience required, high quality filter material may be expensive or not available, risk of clogging if not well pretreated wastewater
(Morel & Diener, 2006)

6.5.3. Treatment ponds

Treatment ponds are large, artificial bodies of water that treat wastewater through natural processes. Usually a combination of ponds is used, anaerobic, aerobic/facultative, and maturation ponds, each designed taking into consideration different parameters. In anaerobic ponds, treatment is primarily due to two different mechanisms: sedimentation and anaerobic degradation. They are between 2 to 5 m deep and with a relatively short hydraulic retention time of 1 to 7 days, up to 60 % of BOD can be removed. Anaerobic ponds can handle strong wastewater, but not without easily avoiding bad odor. Next, in an aerobic/facultative pond, a symbiosis of algae and bacteria further the removal of BOD. The water depth should be between 1 to 2.5 m with a hydraulic retention time of between 5 to 30 days. BOD_5 concentration should be below 300 mg/l (Sasse, 1998). Even though the BOD and TSS and pathogens may be considerably reduced, a further pathogen reduction can be accomplished through the addition of a maturation pond. A maturation pond is the shallowest with a depth between 0.5 to 1.5 m. The pathogen removal mechanisms are mainly due to natural decay (algae activity, UV-radiation, lack of energy source for fecal coliforms), adsorption to suspended solids and sedimentation, and grazing by protozoa. (Tilley et al., 2008)

Wastewater treatment in ponds is one of the most widespread treatment types in the world. It is a popular method because of its simplicity, cheapness and efficiency in removal of the organic load, the efficiency being correlated to the retention time of the water in the ponds. However, treatment of nutrients in ponds is very limited, so if purer water quality is desired, further treatment is required.

- Advantages: High pathogen reduction, low operating cost, no problems with flies or odors when designed correctly
- Disadvantages: requires large land area, effluent requires secondary treatment and /or appropriate reuse or discharge

6.5.5. Complementary treatments

Chemical precipitation

The above treatment types can be combined with extra treatments to further remove nutrients and contaminants from wastewater. Chemical precipitation is a common method used. For precipitation of phosphorous, an appropriate chemical for a farm is lime. If lime, or slags that contain Ca, are used to precipitate the phosphorus, the material can be used in agriculture afterward, which is particularly suitable for soils with low pH [1] (Hylander & Simán, 2001).

Sanitization of feces through ammonia

For feces to fulfill requirements in agriculture pathogens need to be reduced to a safe level. This can be achieved through several different methods, such as an increase in pH to over 11, through sufficiently high temperatures or by adding urea. Urea is a more reliable way to sanitize feces than through mere addition of alkaline drying materials such as lime. The effect is longer lasting. When in contact with water and urease, urea transforms into ammonia. The inactivation of pathogens is dependent on the ammonia concentration, storage time and pH. The urea concentration should be about 2-4% of the substrate weight. At ambient temperatures of 24°C and a 2% wet weight addition of urea, 2.5 months storage time is required to achieve a 3 $\log_{10}$ reduction of *Ascaris* eggs and a 7 $\log_{10}$ reduction of *E.coli.* A combined addition of ash + urea to feces gives an even quicker inactivation of pathogens. (Nordin, 2010)

Sanitization of feces through composting

In the composting process, microorganisms break down the organic matter and heat is produced. Sanitization of feces can even be achieved through thermal composting where the exposure to high temperatures for a decent amount of time is responsible for the inactivation of pathogens. A temperature of 50°C or more is required for around 7-9 weeks (or a couple weeks according to WHO (2006)). For the composting process to work well, several conditions need to be met. Moisture, oxygen, temperature, pH, carbon content and nutrient content all need to be at proper levels. (Svenskt Vatten, 2010)

6.6. USE AND/OR DISPOSAL

When products from treatment system are used or disposed, it is essential that they pose no threat upon the health of handlers and consumers or the environment. Therefore established guidelines/legislation should be followed. It is the use/disposal of wastewater and fertilizer that determines the necessity and suitability of treatment.

6.6.1. Fertilizer/soil amendment

(Suitability: Dry source separation, Wet source separation)

The products obtained from the dry and wet source separation approaches, that is urine from both approaches and dehydrated feces from the first approach, can be used as fertilizer and soil amendment.

[1] Which seems to be the case here at Ceasip

Urine application

Stored urine poses little threat in reuse due to its nearly sterile and self-sanitizing properties. It is a concentrated source of nutrients and can be used to replace all or some commercial fertilizers. It is especially beneficial for crops lacking in nitrogen. The application must be adapted to the particular needs of the crops and depending on soil. A few possible uses are to mix urine undiluted into soil before planting, to pour into furrows a short distance from plant roots (one or a couple times per growing season) and to dilute several times for frequent watering (up to a couple times per week) around plants. (Tilley et al., 2008) Large-scale application in fields can be achieved by using tankwagon with trailing hoses (Figure 22).Complete guidelines on urine usage can be found in *Excreta and greywater use in Agriculture* (WHO, 2006) and in *Practical Guidance on the Use of Urine in Crop Production* (Richert et al. , 2010).

Figure 22. Tankwagon with trailing hoses (Source: Johansson et al.(not dated), with permission).

Application of dehydrated feces

Dehydrated feces are especially suitable for application on poor soils with low carbon content since they can provide useful carbon and boost water-holding capacities, but preferably on soils and crops where there is a low risk of pathogen transmission. Since dehydrated feces can still contain pathogens after dehydration, special consideration must be taken before use a complementary treatment must be applied as formerly described. Complete guidelines on feces usage can be found in *Excreta and greywater use in Agriculture* (WHO, 2006) and *Guidelines on the Use of Urine and Faeces in Crop Production* (Jönsson et al., 2004).

6.6.2. Irrigation

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

If wastewater is to be used as irrigation water (which is possible with graywater from the dry source separation approach, the greywater and fecal water from the wet source separation approach and the mixed wastewater in the mixed wastewater approach) then waters should have gone through onsite treatment to limit the risks involved. Reassurance needs to be taken to sustainability health criteria to prevent health risks[1].

[1] This is also evident after the previously mentioned studies performed in Cochabamba where effluents did not fulfill irrigation standards.

According to the WHO guidelines for the safe use of wastewater (WHO, 2006), a risk analysis should be performed for the wastewater or excreta to be reused. This includes risk assessment, risk management and risk communication. If guidelines are followed, all approaches mentioned in this thesis can fulfill health criteria. (Sustainable Sanitation for the 21st Century, 2011)

Reuse of wastewater in irrigation is an excellent way to reduce groundwater depletion and have a constant source of nutrient-rich water for crops. Furthermore, if pond water is used for irrigation, pond algae act as a "slow release" fertilizers as well as contributing to soil organic matter, thus improving the water-holding capacities of the soil. (Mara, 2004) Two main types of irrigation possibilities are drip irrigation and surface water irrigation. Spray irrigation of wastewater should be avoided in order to minimize contact with pathogens and minimize evaporation losses.

In *drip irrigation*, water is emitted from perforated pipes onto or near the root zone of crops. It is the most suitable irrigation type when used on food crops. It also allows for the efficient use of water since unnecessary evaporation and watering of undesired zones is avoided. One problem is potential emitter clogging, mostly due to the soil algae (rather than pond algae) that thrive on the nutrient rich wastewater. The system must be cleaned and maintained to avoid clogging and remove solids that have built up and repair damages. (Tilley et al., 2008)

In *surface water irrigation*, water is routed over-land to crops either through dug channels or furrows. It is not efficient for the amount of water used, but very little infrastructure is needed. Since humans and vectors can more easily come in contact with the water in such a system, it is only suitable for low-risk waters. It requires a sufficient slope from the discharge point to lead wastewater to crops by gravity. (Tilley et al., 2008)

6.6.3. Soak pit

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

A soak pit is a pit that rids of wastewater by allowing it to slowly soak into the ground. It can be lined with a supportive material to prevent collapse, but is open at the bottom and has somewhat porous lining to allow for infiltration. [1] It should be no more than 1.5-4 m deep but never less than 1.5 m from the groundwater table. (Tilley et al., 2008) This is the current wastewater disposal method for three of the connected eastern buildings at Ceasip.

6.6.4. Leach field

(Suitability: Dry source separation, Wet source separation, Mixed wastewater)

In leach fields, a solids-free wastewater passes from the sewer or a collection point to a system of perforated tubes, through a biofilter medium, and finally infiltrates into the ground. The system employs aerobic processes (see *2.3. Anaerobic and aerobic processes*) with which high levels of treatment can be achieved when properly designed

[1] To dispose of treated wastewater either into water recipients or as groundwater recharge is a non-productive way of getting rid of water and to do so requires the strict following of regulations to minimize impacts on underground and aquatic environments.

with unsaturated flow. The system dimensions should be able to handle the organic load as well as the hydraulic load. Most pathogens are removed, and some natural cleaning of nutrients takes place through denitrification and adhesion to the filtering material; depending on the soil, the removal of phosphorus in infiltration systems is limited and varies greatly. In a well-functioning system, the following reductions can be obtained: BOD_7 – 95%, total-N – 30%, nitrification of NH_4^+ - 50%, pathogens - 99-99,9%, total-P – 25-50%. (Ridderstolpe, 2007).

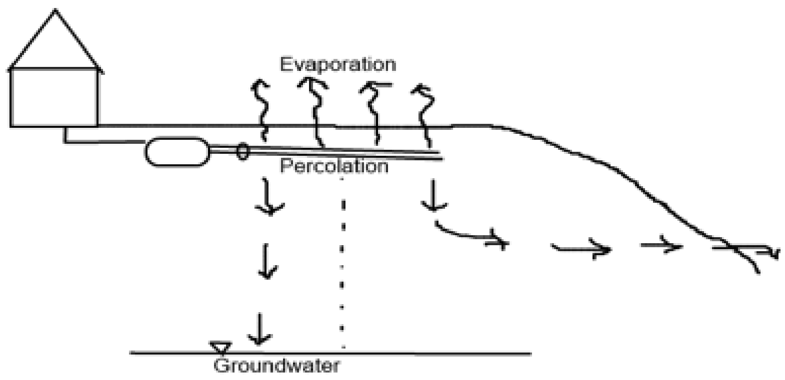

Figure 23 Fate of water discharged to onsite wastewater treatment systems (inspired by EPA, 2010).

Two types of leaching systems are the classic type and the reinforced type. A classic infiltration system, which disperses wastewater directly into the soil and then percolates down to the groundwater as in Figure 23, is acceptable when the soil grain size is appropriate. In the case that the natural conditions are not sufficient to handle hydraulic or BOD loads, a modified or reinforced system is recommended. Extra materials or technology, to spread wastewater evenly over a greater surface and to increase the surface area on which microorganisms grow, should then be used to reinforce the infiltration and treatment before percolation into soil.

Common challenges with leaching systems include to avoid clogging of holes in the perforated pipes and to achieve uniform distribution. Different designs have been invented to cope. Many modern infiltration systems use a pump rather than the slope to allow the whole length of the system to fill at once resulting in more uniform distribution. To avoid clogging, there are examples of designs with the holes at different heights. Another example of a solution to the problem of clogging and uniform spreading is the Norwegian “spray filter” or trickling filter, where the solids-free wastewater gets pumped out as a spray over a biofilter. However, in this study “simpler technology” solutions, such as the systems using slope rather than a pump for distribution are preferred so high technology pump solutions are therefore disregarded.

The particle size of the soil used in leach fields must not be too fine to let the water pass through, nor too big in order for the hydraulic retention to be enough for cleaning to take place before wastewater reaches the groundwater level. See Figure 24 for the grain sizes that are most suitable for infiltration. In zone A, classic infiltration into soil is suitable and may tolerate a hydraulic load of 40-60 l/(m^2·day). If the grain sizes do not fall under this category, but do fall under the category of zone B, infiltration may still be suitable, but with a maximum hydraulic load of 30 l/(m^2·day) and it may also be suitable to reinforce the infiltration/percolation by using an extra material (at least 30 cm of sand) for spreading wastewater and facilitating the establishment of a biofilm. A reinforced infiltration system is recommended in the case that the natural conditions are not sufficient to handle hydraulic or BOD loads, if the grain size of the soil falls outside of the A and B zones.

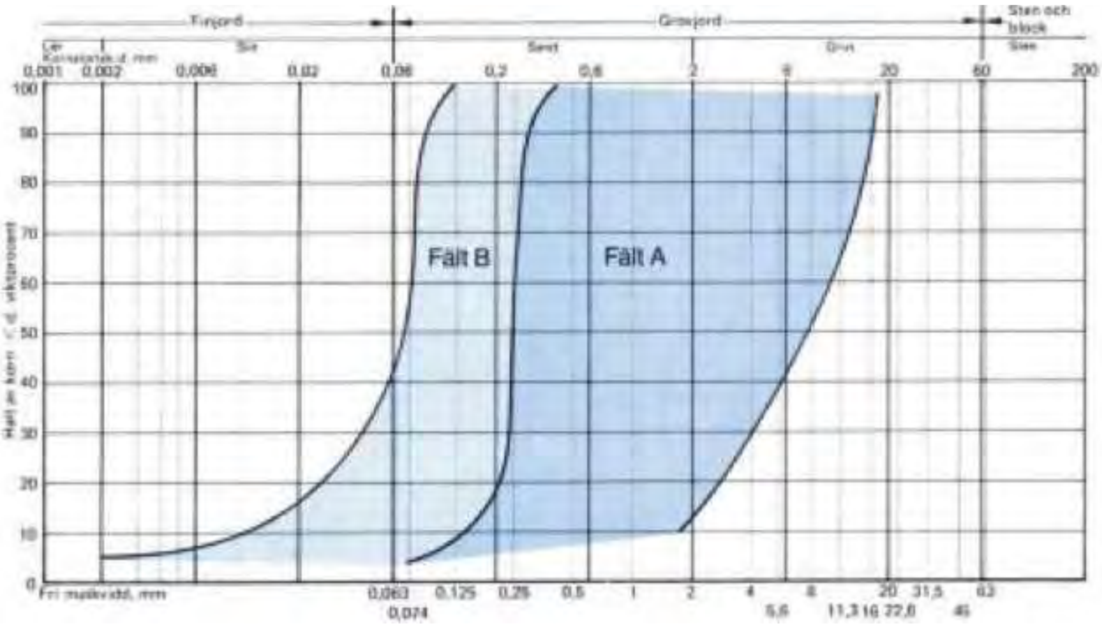

Figure 24. Suitable soils for leach fields, Zone A ("Fält A") in dark blue and Zone B ("Fält B") in lighter blue (Source: Naturvårdsverket, 2003, with permission).

7. SELECTION OF TECHNOLOGIES AND MANAGEMENT APPROACH

In this section the possibilities for suitable wastewater management solutions are narrowed down. Figure 25 shows the selection process and where what sustainability aspects are considered. First, the sustainability criteria are discussed. Technical advantages and disadvantages are given for different options while environmental aspects are discussed considering the prioritized criteria. In order to make the final selections, first the options need to be narrowed down by choosing a management approach. Next the technology selections within the functional groups are finalized.

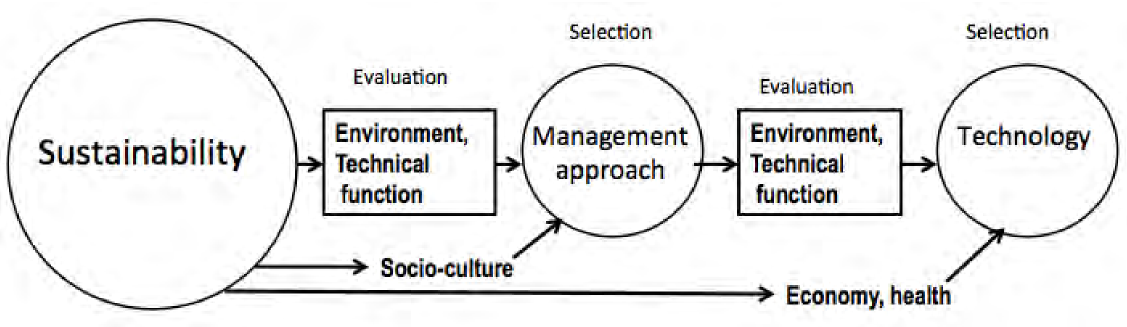

Figure 25. Selection of management and technology by considering sustainability criteria.

7.1. EVALUATION OF SUSTAINABILITY CRITERIA

7.1.1. Economy

Funding was not a central issue for Ceasip, so it was assumed the resources were available for a new and improved wastewater management system as well as training and education of users, especially if the new system supports the foundation's vision. Therefore, specific economic criteria are also eliminated from the management approach selection. Worth mentioning however, is that relatively little time and energy, would be spent by the farm employees to manage and collect urine and/or feces compared to the labor required to collect other organic fertilizers. Urine and feces fertilizers are also free of cost (other than the system investment cost).

It can also be noted that while all the treatment options can produce similar results, generally wetlands require more space and material to achieve the same effluent quality as a secondary facultative treatment pond (Mara, 2004), which would mean that constructed wetlands are a more expensive treatment option than treatment ponds. However, the cost of digging and laying down sewers to a "central" onsite treatment should also be considered. A budget for two different system alternatives is displayed in Appendix 5.

7.1.2. Health

Correct management of sanitation systems is assumed, which eliminates health criteria from the first stage of decision-making, selection of management approach. The management aspects are given briefly in the theory and review of relevant technology sections.

In the second stage of decision-making, pathogen reduction (measured by *E-coli* reduction) is considered.

7.1.3. Technical function

The technical function from the sustainability criteria previously defined is evaluated for all the different technology functional groups in tables 22-26. Some key points are summarized as well as advantages and disadvantages roughly summed up. In all the functional groups, the different alternatives are compared to the present systems in use at Ceasip and it is assumed that all technologies would be used and maintained correctly. Onsite treatment does not currently exist except for partial treatment in septic tanks and soak pits; therefore, onsite treatment alternatives are compared to *septic tank + soak pit*.

Table 22. Technical criteria for user interfaces, setting the current as a '0' and comparing the others to it as better´+', worse'-', or no considerable difference'0.' The summed or total evaluation is given in the last column "Evaluation."

User interface	Feasibility	Simplicity	Maintenance	Durability	Evaluation
Ordinary flush toilet	0 available, common	0 some parts	0 clear blockages occasionally cleaning	0 porcelain durable small parts wear out	0
Urinals	0 available	- 0 + depends on type	0 prevent pipe clogging occasionally	- 0 + depends on type	0
Eco-toilet	0 available	+ not many technical parts, no constant water source needed	- prevent pipe clogging, cleaning more difficult	+ not many parts that can break	+
Wet eco-toilet	- not locally available	- more parts than Ordinary flush toilet	- prevent pipe clogging	0 porcelain durable small parts wear out	-

Table 23. Technical criteria for collection and storage, setting the current one as a '0' and comparing the others to it as better'+', worse'-', or no considerable difference'0.' The summed or total evaluation is given in the last column "Evaluation."

Collection and Storage	Feasibility	Simplicity	Maintenance	Durability	Treatment efficiency	Evaluation
Septic tank	0 available	0 not many parts	0 occasional sludge pumping required	0 long service life	0 reduction of solids and some organics	0
Urine storage tanks/containers	+ available, easy to buy	+ - jerry can: very simple tanks: pump required	- frequent emptying if small, heavy to carry Easy to clean	0 plastic materials durable	+ more efficient pathogen treatment with longer storage	+
Dehydration vaults	0 locally available materials and contruction	+ more simple construction	- manual emptying 2x/year Drying material should be added Some	0 cement vaults give long service life	0 some natural treatment but certain pathogens may persist	0
Baffled reactor	- locally available materials but Requires expert construction	0 no advanced technology	0 occasional sludge pumping required	0 long service life	+ high reduction of organics	0
Anaerobic filter	- locally available materials but Requires expert construction	0 no advanced technology	0 occasional filter cleaning required	0 long service life	+ high reduction of organics	0

Table 24. Technical criteria for conveyance, setting the current one as a '0' and comparing the others to it as better'+', worse'-', or no considerable difference'0.' The summed or total evaluation is given in the last column "Evaluation."

Conveyance	Feasibility	Simplicity	Maintenance	Durability	Evaluation
Simple sewer	0 locally available materials and contruction	0 precison in design	0 some unclogging	0 prone to damage from above	0
Solids-free sewer	0 locally available materials and contruction	0 more septic tanks but less inspection chambers	+ less solid build-up in pipes.	0 prone to damage from above	+
Human powered emptying and transport	0 employees and materials available	- + depending on if pump is used no constant water source required	- regular routines need to be established	0 not applicable	-

Table 25. Technical criteria for onsite treatment, setting the current one as a '0' and comparing the others to it as better'+', worse'-', or no considerable difference'0.' The summed or total evaluation is given in the last column "Evaluation."

Onsite treatment	Feasibility	Simplicity	Maintenance	Durability	Treatment efficiency	Evaluation
Septic tank + Soak pit	0 available	0 simple for all users	0 occasional desludging	0 long service life	0 little treatment may affect soil or groundwater negatively	0
Sand filter	0 filter material available	- more parts where precision is needed	0 inspection of pipes, chambers occasional cleaning	- long BOD service life short nutrient service life	+ high BOD & pathogen reduction some nutrient removal	-
Wetlands	0 locally available materials and contruction	- requires great quanitities of materials	- possible harvest of plants ensure that liner does not get damaged by tree roots etc.	- replacement of filter material every 8 to 15 years	+ good BOD reduction good pathogen reduction	-
Treatment ponds	0 locally available materials and contruction	+ very few technical parts	+ desludging every 10 to 20 years	- 0 + depending on potential harms to liner and adequate pretreatment	+ good BOD reduction high reduction of pathogens	+
Chemical precipitation					+ high nutrient removal	

Table 26. Technical criteria for use or disposal, setting the current one as a '0' and comparing the others to it as better´+', worse'-', or no considerable difference'0.' The summed or total evaluation is given in the last column "Evaluation."

Use or disposal	Feasibility	Simplicity	Maintenance	Durability	Treatment efficiency	Evaluation
Soak pit	0 common	0 simple for all users	0 very little	0 long service life	0 may affect soil or groundwater negatively	0
Leach field	- physical conditions difficult reinforced filtering material available	- more parts where precision is needed	0 inspection of pipes, chambers occasional cleaning	- long BOD service life short nutrient service life	+ high BOD & pathogen reduction some nutrient removal	-
Fertilizer/soil amendment	0 available materials very suitable physical conditions special need for training	- 0 + depending on the methods	- regular routines need to be established	+ soil restoration and durability	+ continued treatment in interaction with soil and crops	+
Irrigation	0 available materials very suitable physical conditions special need for training	- pump may be necessary	- regular routines need to be established	0 damages may be done to the sytem	+ continued treatment in interaction with soil and crops	-

Summary - technical function

It becomes clear from the tables that some options are more or less technically advantageous.

- Of the user interfaces evaluated, compared to the current ordinary flush toilets, eco-toilets are a very good technical option while wet eco-toilets are a more technically difficult option.
- There are no huge differences in the evaluation scores of collection and storage/treatment except that the separate storage of urine also simultaneously provides a highly efficient sanitization of the product. The source separating storage options are more technically demanding regarding upkeep, but are on the other hand technically simple.
- Conveyance of wastewater and input products could be improved from the current sewer system by using a solids-free sewer system. If Dry source separation or Wet source separation is chosen, some human powered emptying and transport is unavoidable although it may be unenticing.
- Of the onsite wastewater treatments compared, a technically sound and simple option is treatment ponds.
- In use/disposal options, fertilizer/soil amendment shows most technical benefits considering that there is the opportunity for close and direct application. Leach fields and irrigation show more technical challenges.

7.1.4. Environment

Use and/or disposal and Onsite treatment are the functional groups of interest for comparing environmental criteria in order to choose a management approach. The other functional groups (User-interface and Conveyance) cannot be directly compared. Since different sources were used to find the efficiency of the different technologies, the numbers can only be compared approximately.

The prioritized criteria, prevention of contamination of groundwater and surface water, reduction of groundwater usage, potential use of wastewater and potential recycling of nutrients were evaluated along with treatment efficiencies in Table 27 below. Only the wet source separation and mixed wastewater approaches are given in the table since the Dry source separation is not comparable in all the functional groups. In addition, other relevant information is mentioned in the text.

Nutrients

Due to the poor, fragile soils previously described, there is a great need for fertilizers at Ceasip to facilitate production. If urine were to be collected from all the farm buildings and according to nutrient flow calculations combined with the present condition results, 1.3-4.4 ha of a few crops could be provided with urine fertilizer considering N-need while 0.7-1.6 ha could be fertilized considering P-need.

While these results only show the nutrients for N and P, it should be noted that urine also includes other essential nutrients. Also, the stated N and P values can be discussed. First of all, the first calculations are based on the assumption that 1/3 of employees' daily excreta is collected which may or may not be reasonable, since currently many employees seem to prefer to relieve their needs outside closer to their work field. Next, it is also possible that many employees used the toilets without wanting to "admit" it. With the correct training and encouragement, it seems likely that the proportion of excrement collected could increase. In a future, if more employees join the farm and with more visitors, this would undoubtedly increase the nutrient flows. Finally, nutrient need varies for different crops and the above stated values only consider a few investigated crops.

Water usage

Reuse of wastewater is an effective way of decreasing usage of ground water. At Ceasip, the majority of field crops are not currently irrigated, which also means that production is limited, especially during drought periods. If it is possible to store wastewater for longer periods of time, for example store it during the wet season and wait to use it till the drought period, assuming that the wastewater to be used for only one grow period (approximately 120 days) per year. That gives us 365-120 days = 245 days of possible accumulation. With the current wastewater production from the four eastern buildings, that would give 1620 l/day ·245 days = 396 000 l (or 396 000 mm · m^2) per year excluding evaporation losses from the ponds. For a typical crop at Ceasip like sorghum, the wastewater volume would be enough to cover the water need of about 610 - 862 m^2, in other words 6-9% of 1 ha (according to the values in Table 10 that give 396 000/650 and 396 000/460). If the drought lasts for shorter time period, then the wastewater could be accumulated for even more time and cover a higher percentage of the water need. A more specific study of the climate and actual water needs would better show the significance of these values.

Energy

Also worth mentioning regarding the environmental criteria is the amount of energy that can be saved by applying excreta as fertilizer and by using wastewater as irrigation water. According to Johansson et al. (not dated), urine can be transported as far as 220 km by a tank truck and trailer before energy consumption exceeds that in the conventional system (in European conditions, that is using mineral fertilizers and if wastewater were to be treated in a conventional European treatment plant). So for the urine to be used onsite with at most only 2 km transport stretches, the reduction of energy consumption in crop production is certainly significant.

Table 27a. Evaluation of environmental criteria for technology options within Use/disposal (According to Morel & Diener (2006); Sasse (1998); Ridderstolpe, (2007); Naturvårdsverket (2003), and Mara (2004))

	Use/disposal			
Environmental criteria	**Leach field**	**Soak pit**	**Irrigation**	**Fertilizer/soil amendment**
Prevention of contamination of groundwater (little or no prevention:1, some prevention:2, high prevention: 3)	2	1	3	3
Potential for reduction of groundwater usage (little or no potential:1, some potential :2, high potential: 3)	1	1	3	2**
Potential for recycling of nutrients (little or no potential:1, some potential :2, high potential: 3)	1-2*	1-2*	2	3
Evaluation totals	**5**	**4**	**8**	**8**

*some potential if complementary treatment like precipitation is used

**carbon adds water retaining qualities to soil and urine adds water

Table 27b. Evaluation of environmental criteria for technology options within Onsite (According to Morel & Diener (2006); Sasse (1998); Ridderstolpe, (2007); Naturvårdsverket (2003), and Mara (2004))

	Onsite treatment							
Environmental criteria	**Sand filter**		**Wetlands**		**Treatment ponds (combined effect)**		**Leach field**	
Removal efficiency: (low: 1, medium: 2, high: 3)								
BOD	90-99%		80-90%		~90%		90-95%	
TSS	85-95%	3	80-95%	3		3		3
Total N	10-40%		15-40%				20-40%	
Total P	25-50%	2	30-45%	2		1	60-80%	2
Greases								
Coliforms	~2log	2	<=2-3log	2	3-6 log	3	2-3log	2
Evaluation totals		**7**		**7**		**7**		**7**

Table 27c. Evaluation of environmental criteria for technology options within Collection and storage (According to Morel & Diener (2006); Sasse (1998); Ridderstolpe, (2007); Naturvårdsverket (2003), and Mara (2004))

	Collection and storage					
Environmental criteria	**Septic tank**		**Anaerobic baffled reactor**		**Anaerobic filter**	
Removal efficiency: (low: 1, medium: 2, high: 3)						
BOD	~50%		<=90%		50-80%	
TSS		2	<=80%	3	50-80%	2
Total N	10-15%		<= 20%		<=15%	
Total P	10-15%	1		1		1
Greases			~70%			
Coliforms	~1 log	1	~1 log	1	<=1-2log	1
Evaluation totals		**4**		**5**		**4**

Summary - environment

Sustainability criteria are discussed for the different functional groups, assuming correct management of each group.

- Of the user interface options, the eco-toilet is the only option that plainly fulfills the criteria of reduction of water use (excluded from tables).
- Of the collection and storage options, urine storage tanks preserve the nutrients in plant available forms while the other options reduce the amounts of plant available nutrients (Table 27).
- The conveyance options compared do not directly affect the sustainability criteria (excluded from table).
- Of the treatment options compared, all options can to a large extent prevent groundwater contamination (Table 27).
- Of the use or disposal, fertilizer and irrigation can aid in both avoiding groundwater contamination and in recycling nutrients, while the soak pit and leach field do not recycle nutrients but might possibly contaminate groundwater (Table 27). To precipitate P with lime could be a compromise (excluded from table).

7.1.5. Socio-cultural

Considering the difficulty of the task, the socio-cultural criteria were not quantitatively analyzed in this thesis as a basis for decision-making. However, they were considered as a "veto" criteria with the power to ultimately influence the choice. The socio-cultural criteria were essential in the choice of sanitation systems and wastewater treatments. Since experiences from NGOs and organizations showed that it was more difficult socially for people with wet flush toilets to change to dry toilets, whereas it was easier for people with non-improved sanitation or pit latrines to "upgrade" to dry eco-toilets (Burela, pers. comm. 2011), this means that an eco-toilet would not be so appropriate in the context of the farm where everyone is accustomed to ordinary flush toilets, unless great efforts are made in education. With both eco-toilets and wet eco-toilets, there is a need for user and management education. On a national level, it was observed that even in locations that receive many tourists and have middle-upper class residents, toilets and bathrooms were often not prioritized, neither in comfort level, nor construction quality. This suggests that there are extra social challenges involved with training.

Because Ceasip is a research farm, research on the functionality of urine and feces fertilizers was deemed appropriate. The possible benefits of the use of such fertilizers support the vision of the Foundation Simon I. Patiño.

Semi-formal interviews and conversations with people at Ceasip or with some relation to Ceasip showed that certain acceptance of a different sanitation system was possible. There was a certain openness to try new toilet solutions if it benefits the sustainability cause. There was much reluctance to reuse excreta as fertilizer but when presented with the "if safe and beneficial" argument, there was some acceptance. They were however not prepared to put in extra hours at home to "take care of" excreta. For some, a new solution could only be accepted if the user interface was easy to clean, as well as there being no smell. Others were not prepared to test new solutions in their own home, but were willing to try at other locations (like at work). At least one farm employee already had and used an eco-toilet at home and was therefore totally open to the use of such toilets on the farm. This employee did not think however that other employees would easily accept the change. Some workers on the farm knew of the values of excreta such as medicinal value and plant nutrient value. Considering that there is certain taboo and embarrassment regarding the topic of excreta and sanitation, although not everyone is shy, it is difficult to know the accuracy of statements made by people interviewed.

7.2. MANAGEMENT APPROACH SELECTION

According to the technical functions, the Dry source separation shows the most advantages. Dry source separation, ranks the highest technically and fulfills all the prioritized sustainability criteria of reduction of water usage, prevention of groundwater contamination, and possible recycling of plant nutrients. However, socially, practically and realistically, it would be best to install a more sustainable wastewater management system gradually. Therefore the socio-cultural veto is used against Dry source separation at this stage in the selection process to avoid implementing a management approach that would not be fully accepted.

Despite that it is more technically advanced, Wet source separation is a compromise that still fulfills the prioritized sustainability criteria and the best option considering the social conditions. This would allow for a gradual change including mixed domestic wastewater and fecal water to be treated jointly. However, due to the high investment costs, this may be a difficult option for "normal Bolivians" to copy. On the other hand, by starting urine separation and urine experiments, Ceasip would be a positively good leading example.

If and when this is accepted and gives good results, it should be easier to accept Dry source separation for the new buildings and expansion that are being planned. It is likely that people would accept proposed solutions as long as they understand the benefits and if they are sufficiently practical, although to arrive at that point may require some reassuring and persuading. Using Dry source separation, would lead to the necessity of graywater management from the future buildings. It could be combined with the chosen system for the present buildings with only minor modifications.

7.3. TECHNOLOGY SELECTION

Assuming then the use of the wet source separation approach, this means that the user interface and technology choices of the other functional groups are limited. The remaining technology is selected by starting with the use/disposal functional group. It is the use/disposal of wastewater and fertilizer that determines the necessity and suitability of treatment.

As mentioned before, irrigation is a disposal/use system more technically advanced than the current disposal system. However, in environmental sustainability criteria, irrigation and fertilizer/soil amendment rank the highest (Table 27). Applying Wet source separation leads to the possibility of reusing wastewater in irrigation and using urine as fertilizer. Considering how much fresh water is used in the watering of fruit and vegetable crops in the garden, providing irrigation with recycled water, is an efficient way of reducing the use of ground water.

Supposing that the wastewater treatment system then needs to achieve decent irrigation quality, the system should be designed with consideration to the irrigation guidelines[1]. The parameters that need correction in to order to fulfill the established guideline values according to Table 15 are fecal coliforms and nitrogen. Wet source separation of urine should take care of the nitrogen problem since most nitrogen found in domestic wastewater is from urine. If 60% of all urine from the four eastern buildings is collected and using the wastewater quality results, this would give new nitrogen concentrations of 24 mg/l after urine separation, thus complying with the irrigation water guidelines for only slight to moderate restriction on use. This would allow for controlled application nitrogen rich urine at the appropriate times instead of possibly harming plants or risk leaching of nitrogen. The only parameter which then exceeds the guidelines is the concentration of fecal coliforms. The onsite treatment that is most effective in reduction of coliforms is a system of treatment ponds. Considering there is space, it is technically simple, cheap, requires little maintenance and a storage pond would need to be constructed anyway to be able to store water for irrigation, it makes sense to choose treatment ponds as "Onsite treatment."

Two alternatives for different technology selections (illustrated in Figure 26 and Figure 27) are proposed in accordance with the discussions above. Alternative 1 involves a common onsite treatment and reuse of wastewater, which is especially suitable for larger flows, while Alternative 2 focuses on keeping the wastewater sources as they are or separate, for smaller individual treatment. The technology for the different functional groups is clarified as follows:

ALTERNATIVE 1

- User interfaces: *Wet eco-toilets* and *urinals* allow the wet source separation approach.
- Collection and storage/treatment: *Septic tanks* for each household should be designed to separate solids and grease. In buildings where no toilets are installed, a grease trap may be used instead. For the domestic wastewaters, the BOD levels are already low enough that the removal efficiency achieved with a septic tank is deemed sufficient when a subsequent onsite treatment method is used.
  Urine tanks are required for the holding and storing urine.
- Conveyance: *Solids-free sewer system* is the best option considering the very small slopes on property and the history of clogging problems of the current sewer system. This also brings potential clogging and problems closer to the user, which may motivate users to be more responsible about what gets flushed down the toilet or put down the drain. Also little water is necessary to keep pipes clean, which will allow for more water-saving solutions to be installed in the future without having a negative effect on the sewer system.
  Hand powered emptying and transport may also need to be employed to some extent for the handling of urine.
- Onsite treatment: If wastewater is to be used as irrigation, it will need to be stored first. *Treatment/storage ponds* is an economic option and efficient in reducing those parameters which analyses showed as restricting for irrigation. An anaerobic pond is not needed when septic tanks are used.

[1] In turn, the irrigation guidelines consider health criteria.

- Disposal/reuse: *Drip irrigation* is the safest method for reuse of wastewater. It saves water and requires little operational work after installation.

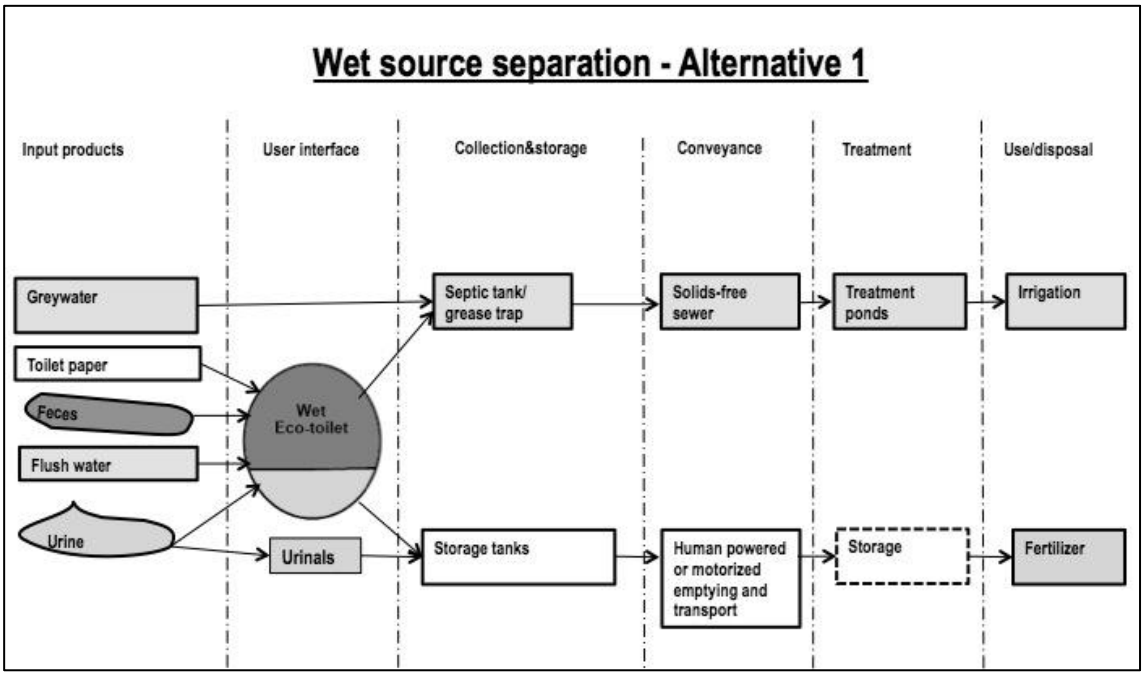

Figure 26. Schematic overview of functional groups for wastewater system with treatment ponds.

ALTERNATIVE 2

Alternative 2 is proposed as another option but still applying Wet source separation. Here, wastewater is disposed rather than reused which detracts from sustainability and potential benefits since water and nutrients are lost from the system. However, protection of groundwater would still be improved compared to present conditions and the recycling of a large portion of nutrients would be made possible through urine separation. The technology selection for Alternative 2 is the same as Alternative 1 in the first three functional groups. The technology that differs is as follows:

- Onsite treatment: Treatment is divided up into smaller units, namely *leach fields*. They should be reinforced because of the physical conditions. Figure 27 also shows *sand filters* as an option since it is basically the same thing as a leach field, except that the wastewater is collected afterward.
- Disposal/reuse: Treated wastewater is disposed of as groundwater recharge/infiltration through leach fields or possibly reused in small-scale plot irrigation after a sand filter (Figure 27).

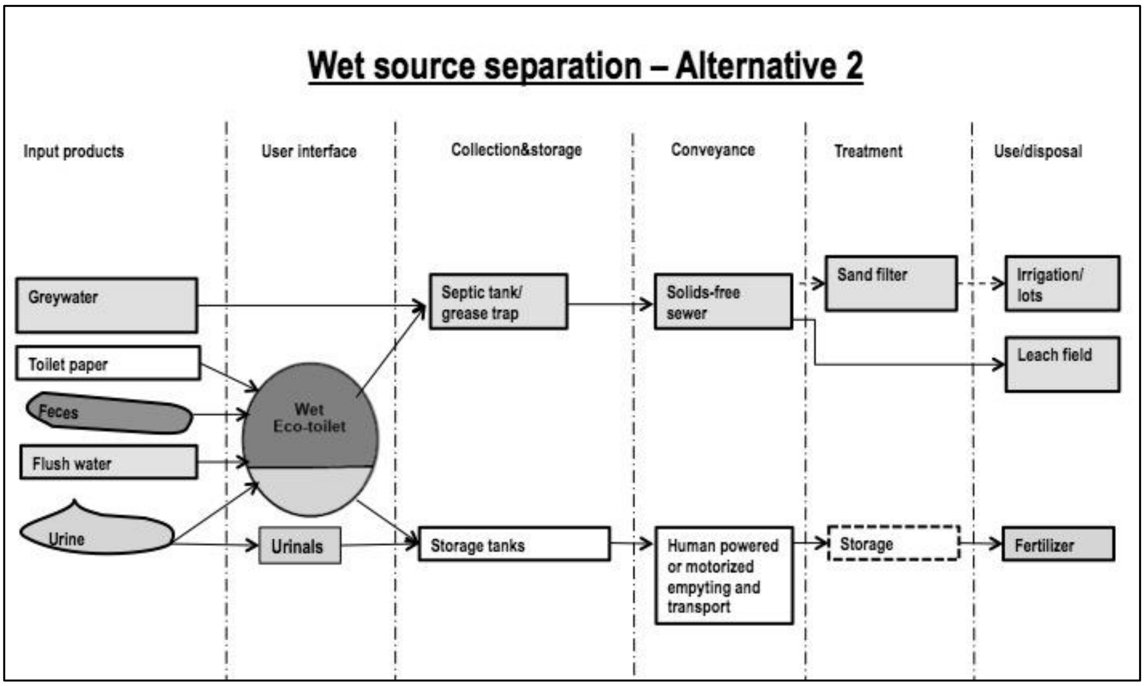

Figure 27. Schematic overview of functional groups for wastewater system sand filters/leach fields.

8. SYSTEM DESIGN

The two alternatives stated in *7.3. Technology selection* are designed in this section, both apply the wet source separation approach, meaning that urine is separated from fecal and graywater using wet eco-toilets and urinals. In this section, the design follows the same order as the functional groups in the previous sections, namely *User interface*, *Collection and storage*, *Conveyance*, *Onsite treatment*, and *Use and/or disposal.* Although the present condition results are for the mixed wastewater approach, it was assumed that similar water use and wastewater collection could be applied for Wet source separation; therefore, hydraulic dimensioning criteria here will be the same.[1] To have a safety margin in dimensions and because the difference in flows between Wet source separation and Dry source separation is fairly small, the water flow values from present conditions apply.

8.1. ALTERNATIVE 1. TREATMENT PONDS AND IRRIGATION

An overview of Alternative 1 is given in Figure 28. It shows that the urine is collected separately while the fecal water and graywater is collected in septic tanks and then treated in a system of ponds to finally become available for irrigation. This design focuses on the four eastern buildings consisting of houses, an office and a cafeteria. The same buildings and treatment overview are shown from above in a topographic map in Figure 29 further on. According to the topographical map and the property survey, possible treatment placement for the wet source separation or mixed wastewater approaches was chosen so that the wastewater could flow with a natural slope in solids-free sewers and avoid pumps, while still being able to connect the eastern buildings of the farm. A tactical location for the storage pond is beside the large lagoon from where it would also be easy to reuse in irrigation.

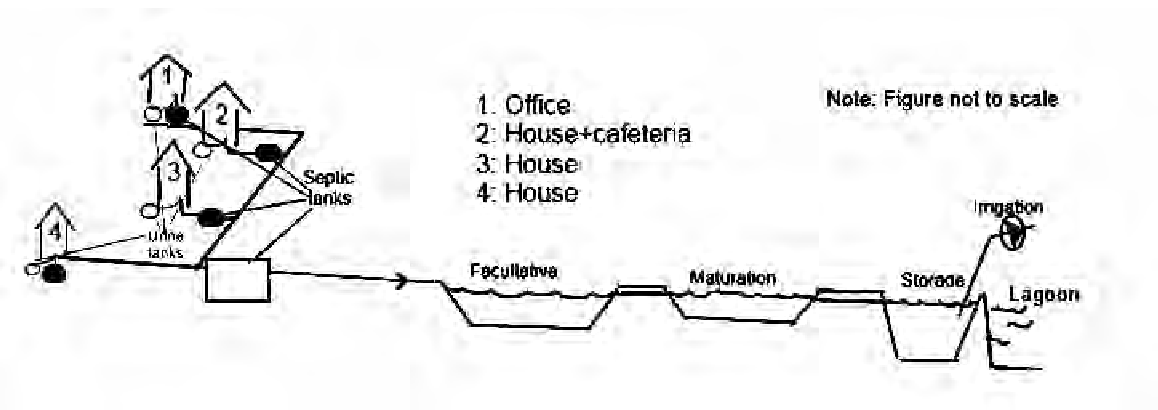

Figure 28. Schematic overview of suggested wastewater management, Alternative 1.

[1] In reality, flows would be reduced per person because wet eco-toilets use less water for flushing than the current ordinary flush toilets and since both urine and some flush water are diverted to a separate tank. But with consideration to the future conditions, because of expanding operations there may also be a higher frequency of toilet use in the public restrooms, which would increase flows.

A summary of the dimensions of suggested tanks and ponds are summarized in Table 28 and Table 29 while the calculations and assumptions are described in more detail for each functional group thereafter.

Table 28. Collection and storage, possible tank dimensions for Ceasip

	Urine tanks		Septic tanks	Grease traps
	Yearly required volume (l)	Suggested tank volume (l)	Suggested volume (l)	Suggested volume (l)
Office	6480	1000-2000	1000-2000	-
Households	4500	1000-2000	1000-3000	-
Cafeteria	-	-	-	300

Table 29. Onsite treatment, possible dimensions for treatment and storage ponds

	Facultative pond	Maturation pond	Storage reservoir
Surface area (m^2)	8.2	14	4
Length (m)	5	7	2
Breadth (m)	1.7	2	2
Depth (m)	1.5	1	2

8.1.1. User interface

Wet eco-toilets and urinals

In the current conditions, if 4 public toilets for employees were installed (wet eco-toilets as described in section *6.2.4)*, and each household installed 1-2 new toilets, this would amount to a total of approximately 10 toilets at Ceasip.

Urinals were already installed in public toilets and at least one household. Adjustments need to be made in piping to lead the urine to an appropriate collection tank. To facilitate urine separation for men, it may be desirable to install more urinals even in the households on the farm if eco-toilets or wet-eco toilets are to be used.

8.1.2. Urine: Conveyance

Conveyance of urine from the user interface to the collection/storage tanks should fulfill the following criteria:

Pipes

- Inclination of at least 1%
- Diameter at least 75 mm but preferably 110 mm (or approx. 4 in)
- No metals or harmful substances that can be released or react with the urine
- Design should allow for easy inspection and cleaning

(Johansson et al., not dated)

8.1.3. Urine: Collection and storage

Urine tanks

Tank dimensions: OFFICE

The most appropriate urine holding/storage type for a large farm with potentially large number of users (especially when there are visitors) are tanks. According to Johansson et al., (not dated), a wet flush, urine separating toilet like those produced by Wostman Ecology requires a 900 l/person & year storage volume, for residents who are at home for 13-15 hours per day. Therefore, for an office where employees work 8 hours per day, about 60% of the storage would be required, that is 540 l/person per year. However, in the case of Ceasip there are employees in the office who use toilets frequently as well as other employees and visitors who only use the office toilets occasionally. If the average number of full-time employees in the office is 6 persons, then the tank dimensions should at least be doubled to provide for other employees and visitors.

→Volume required 12 persons · 540 l/person per year = 6480 l

Seeing as how that may be an unrealistically large tank to dig for, it would make more sense to install a couple smaller tanks, like one for each side of the bathrooms and empty more frequently. That way also the distance required for pipes would be minimized, slopes in pipes could increase, and the blockages would be better prevented.

If 2 holding tanks are used, with a volume of 1000-2000 liters, this should allow for 6 months use before emptying is required.

These could be emptied into a larger storage tank in a size locally available, approximately 5000-6000 liters to allow to store for approximately 6 months to obtain a completely safe fertilizer for application.

Tank dimensions: HOUSEHOLDS

The household toilets are likely used for more hours during the day than the office. Using Wostman Ecology default values of 900 l/person per year and assuming an average of 5 persons/household, this would give a necessary yearly storage volume of 4500 liters. Even in this case however, it seems more practical to use a smaller holding tank. A 1000-2000 liter tank seems suitable even for households.

8.1.4. Urine: Conveyance and use/disposal

Emptying and transport

Either human powered or motorized emptying/transport will be necessary from urine holding tanks. If small-scale, manual application (i.e. fruit and vegetable gardens) is to be implemented, then it would be suitable to use hand pumps and small containers that are easily carried, such as Jerry cans, for transport and storage. If large-scale application in the fields is implemented, it would be more suitable to use vacuum truck and big storage tanks/cisterns.

Fertilizer

Relevant techniques for using urine as fertilizer are described in *Review of relevant technology*. Another option that is currently available at Ceasip is through addition into irrigation distribution net and watering of the vegetable beds and fruit trees manually with the hoses.[1] For large-scale application in fields, a spreader attached to a cistern is suitable.

8.1.5. Fecal water and graywater: Collection and storage

All the buildings on the farm that produce fecal water and graywater (or mixed wastewater) should use septic tanks and or grease traps for collection and storage prior to subsequent treatment. A few different sizes are given below for the different buildings (office, households and cafeteria) considering different flows. There is currently only one big septic tank for all three connected eastern buildings, after the simple sewers. This septic tank can be kept even when individual septic tanks are put in.

Septic tank criteria

Septic tank design is according to criteria by Morel & Diener (2006); the total required volume considers the following:

A. HRT $\geq$ 24 hr at max sludge depth and scum accumulation. Calculate volume from $Q_{dim} \cdot HRT$.
B. Required scum and sludge volume (Calculate sludge accumulation according to TSS and flow results, assuming 50% TSS removal (Tilley et al., 2008) in tank and desludging every 2 years).
C. 1-2 vertical baffles.

Other criteria:

- Placement: septic tanks should be placed at a distance of 1.5-3.5 meters from building. The distance acts as a safety to avoid contamination in case of overflow. See approximate placements in Figure 29 below.
- Maintenance: Desludging frequency should be every 2-5 years.

Grease trap criteria

Grease trap design is according to criteria by (Morel & Diener, 2006):

- HRT = 15-30 min
- V_{min}= 300 l
- 1-2 vertical baffles
- Length/width= 1.3-2.0

OFFICE SEPTIC TANK:

[1] This involves a very precise maneuver so as to avoid contaminating the drinking water with urine. Also, the taps in the gardens that are currently used occasionally for drinking water also would no longer be socially acceptable as drinking water.

As stated previously, the average daily wastewater flow from the office is 540 l (Table 13). Average TSS for the combined eastern buildings was 74 mg/l (in a range of 64-83 mg/l).

Criteria A→ = 0.54 m^3

Criteria B → $74 \cdot 10^{-6}$ kg/l · 540 l/d · 365 d · 2 yrs · 50% = 14.6 kg

This is the dry weight of TSS. There is 20 g TSS/l sludge. (Halalsheh et. al, 2008) So the volume is calculated as follows:

→14600/ 20 = 729 l

So this would mean a storage volume of approximately 0.7 m^3 after 2 years. However, considering that there will be some biological break down of the organics in the sludge, the sludge volume will be reduced which is why scum is assumed within the same volume. If toilet paper is added on a regular basis in the future, this may affect the TSS concentration and more leeway should be considered.

A + B → Total V = **1.3 m^3**

HOUSEHOLDS SEPTIC TANKS: .

A few specific values for collected wastewater for the eastern buildings are stated in Table 12 while a fuller list is given for the specific water flows in Appendix 3.

Table 12 gives for a typical household, the daily water flow of 387 l/day. In case of guests, higher loading, etc., use 400 l/day for some margin. Use the same TSS value as above.

Criteria A→ 0.4 m^3

Criteria B → $74 \cdot 10^{-6}$ kg/l · 387 l/d · 365 d · 2 yrs · 50% = 10 kg

This is the dry weight of TSS. There is 20 g TSS/l sludge. (Halalsheh et. al, 2008) So the volume is calculated as follows:

→10000/20 = 500 l

So allow sludge and scum storage of approximately 0.5 m^3. Although, if toilet paper is added on a regular basis in the future, more leeway should be considered.

A + B → Total V = **0.9 m^3**

These can be compared to the EPA requirements for three-bedroom houses, with septic tanks of 3.4 m^3 – 3.8 m^3 (US EPA, 1980).

Since 0.9 m^3 - 3.8 m^3 is a large span, it is recommended that if prefabricated septic tanks are used, to choose the locally available size that is at least 1 m^3. Choosing a larger septic tank of about 2 or 3 m^3 would ensure that maintenance and desludging is minimized. The same goes for cement septic tanks that are made on the spot.

CAFETERIA GREASE TRAP:

Grease trap for cafeteria is a cheaper option than a septic tank, and should be sufficient if not large quantities of solids are put down the drain. This will allow for the grease to be caught and removed at an early stage. The observed clogging by grease in the present sewage system from the cafeteria can motivate the usefulness of the grease trap

A few specific values for the collected wastewater for the eastern buildings are stated in Table 12 while a fuller list is given for the specific water flows in Appendix 3.

Table 12 gives for cafeteria: Using $Q_{peak} = Q_{dim} = 55$ l/h.

Calculations:

- $V = Q_{dim} \cdot HRT = 55$ l/h $\cdot$ 0.5 h = 27.5 l which is less than V_{min} so choose **V= 300 l**
- Choose for example length = 1 m, width = 0.5 m, height = 0.6 m and 2 baffles.

8.1.6. Fecal water and graywater: Conveyance

Conveyance of fecal water and graywater (and even some toilet wastewater if not all ordinary toilets are changed) to the subsequent treatment should fulfill the following criteria:

Solids-free sewer system

- Pipe diameter of at least 75 mm
- Can be laid at shallow depth
- Few inspection points
- Inflective gradients are ok to some extent if the downstream end of the sewer is lower than the upstream end

Maintenance: should be flushed once a year, regardless of performance.

The current sewer system in Ceasip connecting three of the eastern building is sketched in black in Figure 29 while suggested approximate extensions are sketched in red. To upgrade the current sewer system to a solids-free sewer system means that modifications around the buildings have to be made in order to make space for and connect septic tanks (or grease traps). If the sewer is laid according to the sketch and only considering topography (not pipe depth), then gradients will be between 4 and18‰. (That is assuming that the topography map is correct.)

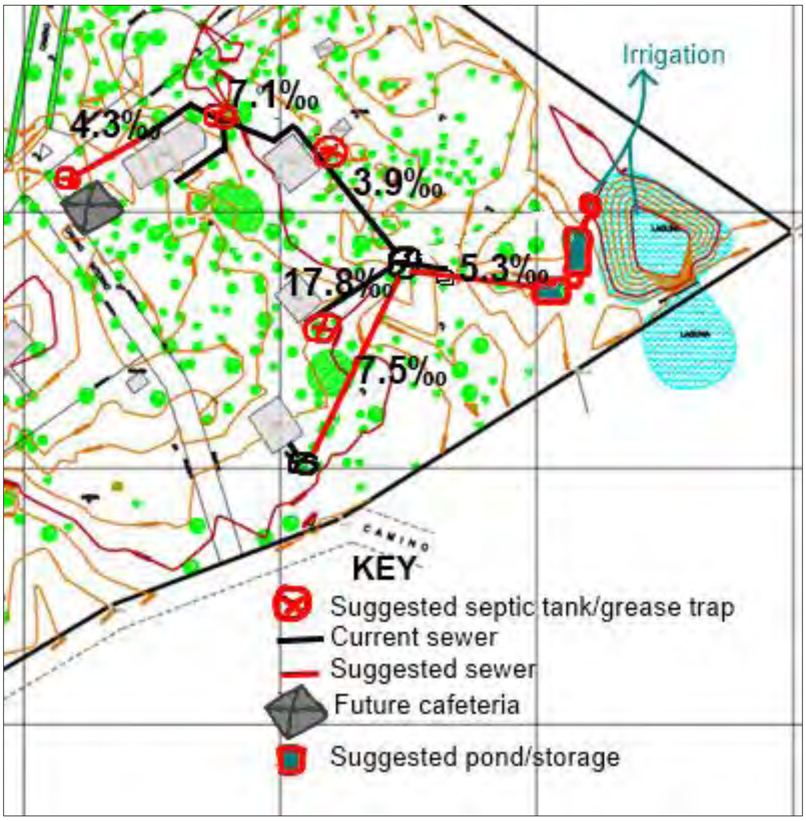

Figure 29. Approximate sketch of current sewer, suggested sewer, suggested septic tank locations and slopes at Ceasip (modified from Ceasip, 2008).

Emptying and transport

Grease from the grease traps should be controlled and emptied manually every couple weeks. This should be incorporated manually to the compost on property. Sludge from the septic tanks could be emptied and transported by a vacuum truck. The quality should be analyzed to determine its suitability of reuse of disposal.

8.1.7. Fecal water and graywater: Onsite Treatment

The onsite treatment focuses on reduction of BOD and pathogens through a series of treatment ponds. A typical effluent from a facultative pond requires further treatment for pathogen reduction, so maturation ponds can help fulfill this function (see *6.5.3. Treatment ponds)*. While the combined wastewater flow from the four eastern buildings was actually 1618 l/day (Table 13), to consider that these results were only for a two-month period and to allow some safety margin while dimensioning, 2000 l/day is used in the designing calculations (divided up into 1600 l/day for the three buildings currently combined and 400 l/day for the other household).

Since wastewater is already previously treated in septic tanks before arriving at treatment ponds, BOD values should be significantly reduced to skip the anaerobic pond and lead wastewater directly to a facultative pond. The specific BOD_5 from the analyses (see Appendix 5) gives an average value of 280 mg/l for the four eastern buildings according to Table 30.

Table 30. Average BOD_5 calculation for the four eastern buildings at Ceasip

	Three connected eastern buildings (Two occasions)		Household (nr 4)	Average BOD_5
BOD_5 (mg/l)	260	350	70	**279**
Flow (l)	1600	1600	400	

BOD reduction in septic tanks according to literature ranges from 30-50% (Tilley et al., 2008), but since we have wastewater that passes through 2 septic tanks (the first is the individual septic tank and the second is a large combined septic tank that already exists in present conditions), assume a 50% reduction. That gives new values of average BOD_5 = 140 mg/l which is the value used in the designing of the facultative pond below.

Facultative pond

Designing of facultative ponds is done according to well-accepted methods and guidelines laid down in *Domestic Wastewater Treatment in Developing Countries* (Mara, 2004).

Facultative ponds are best dimensioned in regards to surface loading area according to Equation 1, (rather than volumetric loading) because of the light needed for algal photosynthesis.

$$\lambda = \frac{10\,LQ}{A} \qquad \text{(Equation 1) (Mara, 2004)}$$

where λ is the surface BOD loading in kg/ha day, L is the actual BOD load in g/l, Q is the flow in l/day and A is the surface area in m^2. The factor 10 is a conversion factor because of the units.

The λ varies according to different temperatures. It can be determined by Equation 2.

$$\lambda = 350\,(1.107 - 0.002T)^{T-25} \qquad \text{(Equation 2) (Mara, 2004)}$$

where T is the ambient temperature in °C.

Applying Equation 2 with local temperature average of 24.7° C gives $\lambda = 342$ kg/ha.

Now applying Equation 1 and formerly presented quality and flow results, this gives (with L= 0.14 g/l and Q=2000 l/day) $\boldsymbol{A = 8.2\ m^2}$.

This gives an approximate hydraulic retention time (HRT) according to Equation 3 (water seepage is negligible and evaporation is disregarded although it may be around 10%).

$$HRT = AD/Q \qquad \text{(Equation 3) (Mara, 2004)}$$

where D is the pond depth. A depth of at least 1 meter should be used (and avoid emerging plants) to avoid nuisance of mosquitoes and flies. (Mara, 2004)

Setting D = 1.5 m, A = 8.2 m^2 and Q = 2 m^3/day gives **HRT = 6.2 days** (which is good, typical HRT=5-30 days.)

The design criteria call for a length: breadth ratio of around 3.

Therefore suitable dimensions are:

- **length = 5 m**
- **breadth = 1.7 m**
- **depth = 1.5 m.**

Maturation pond

An appropriate depth of the maturation pond is 1 m (Mara, 2004). This allows for high pathogen removal while also minimizing the mosquito risk.

The BOD surface loading of a maturation pond should clearly be less than that of a facultative pond, for example 75% (Mara, 2004).

Applying Equation 1 but with only 75% of the surface load, and L = 0.05g/l, this gives us a surface loading area of A = 3.9 m^2.

Applying Equation 3 and setting D =1 m, A = 4 m^2 and Q = 2m^3/day gives HRT= 2 days. This is too short time according to typical HRT of 3-10 days required for high pathogen removal.

Set **HRT to 7 days** and using Equation 3, this gives a new **A of 14 m^2**.

Design criteria call for a larger length: breadth ratio than for facultative ponds in order to enhance plug flow character.

Therefore suitable dimensions are:

- **length = 7 m**
- **breadth = 2 m**
- **depth = 1 m.**

Storage reservoir

At this point, water needs only to be stored until desired usage. The size of the required reservoir depends on the frequency of emptying and the quantity of water used. The results showed that even just the vegetable garden uses greater quantities of irrigation water than the quantity of wastewater that is produced (at least during the dry season.) Although the existing lagoon could be deemed an appropriate reservoir for such storage, some adjustments would need to be made. It is difficult to know the exact effect of runoff water in the future especially considering the recent changes made, with the newly constructed pluvial channels. Also considering the difference in water quality between surface water compared to treated wastewater, since the wastewater is more nutrient rich, it would be better to keep it separated from lagoon water and to use the wastewater first. If there is no risk of the lagoon becoming filled or flooded, a part can be partitioned off to keep from having to dig as much. Since the current lagoon area is around 2 500 m^2, with a volume around 2 500 m^3, if the wastewater of only about 2 m^3/day were to be discharged into the lagoon, it would be so thinly dispersed and undergo such great losses that irrigation during the dry season would become difficult. It would undergo high evapotranspiration losses (the lagoon has a lot of vegetation) and seepage losses (since the lagoon is not lined). If there are continued problems with flooding due to climate and runoff factors, channels leading to and from the lagoon would need to be expanded.

Considering that water is used frequently in the gardens for irrigation, a storage reservoir for that purpose need not be excessively large. Also, a higher crop production could be obtained if areas that are not currently irrigated become irrigated. In the case that there is more wastewater produced than what can be used in crops, there should be a spillway for possible overflow into the lagoon.

Because further treatment is not necessary for irrigation water while in storage, the depth may be greater than previous ponds. This would minimize losses. Assume that water needs a storage time of only 4 days. That would mean a necessary storage volume of less than 8 m^3.

Suitable dimensions are therefore:

- **length = 2 m**
- **breadth = 2 m**
- **depth = 2 m**

If the storage pond is to store water for longer periods of time, it would need to be bigger than previously mentioned, in sizes that are comparable to a larger section of the current lagoon.

An overview of the pond system with suggested dimensions is shown in Figure 30.

Other criteria

- The ponds should be located 200 m downwind from the buildings to discourage people from visiting the ponds and incase of smells. At Ceasip the proposed location does not fulfill this criteria. However, considering the small-scale nature of the suggested treatment, approximately 70 meters from houses is deemed enough. A fence may be put up to prevent visitors from getting too close.
- The hydraulic conductivity (K) should be $<10^{-7}$ m/s (or 10^{-5}cm/s) to be able to retain water sufficiently. In the cases observed shown in results in Table 21, K was too permeable, or borderline to being too permeable to retain pond water. Therefore a lining should be used (i.e. plastic liner). This will also prevent emergent plants from growing and discourage mosquito breeding.
- The base of the ponds should be smaller than that of the embankment. A freeboard of 0.3-0.5 m should be provided for small ponds in order to prevent wind-induced waves from overtopping the embankment.
- Inlet and outlet structures should be simple and inexpensive.
- The earth material dug out to create the ponds can be used as a dike around the ponds to prevent dilution and mixing otherwise due to runoff waters.

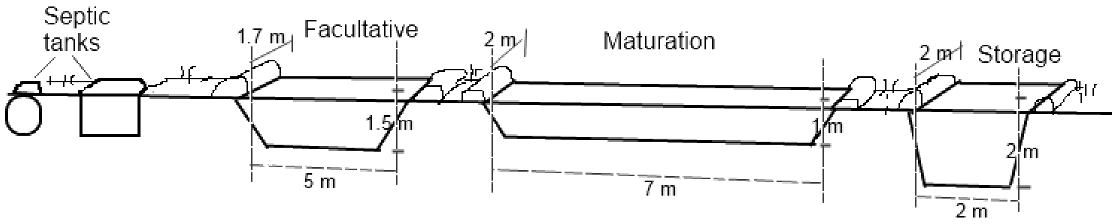

Figure 30. Pond system overview with suggested dimensions.

8.1.8. Fecal water and graywater: Use/disposal

Irrigation: As previously stated in *2.2.1. Risks and guidelines of wastewater reuse* and *6.6.2. Irrigation,* if wastewater is to be reused, special reassurance needs to be taken to sustainable health criteria to prevent health risks. According to the WHO guidelines for the safe use of wastewater (WHO, 2006), by using drip irrigation, yet another health protection barrier is enacted since the wastewater is then applied with more control and there is less risk of pathogen contact with the produce and the humans. Drip irrigation is a low-pressure system, so little pressure (which also means little energy) is required. Although a pump would be needed for irrigation since the proposed treatment and storage are at the lowest points on the property, the pressure and energy required will be significantly less than using groundwater (which is currently pumped up from depth of approximately 20 m down, up to the water tank another 9 m). A number of local entrepreneurs specialize in installing drip irrigation systems.

8.1.9. Future considerations

Potential flow differences need to be estimated for future buildings. If the differences are considerably large, recalculate dimensions of the ponds or consider adding other ponds in parallel.

8.2. ALTERNATIVE 2. LEACH FIELDS/SAND FILTERS

Only the technologies that differ from Alternative 1 are described in this section, namely in functional groups *Onsite treatment*, *Use and/or disposal* and *Conveyance*.

Conveyance in Alternative 2 only differs in that no big extensions of the present sewers need be made. Implement short conveyance routes from each building to its septic tank and then to its leach field. One possibility is to combine the treatment of a couple buildings and another possibility is to have completely individual systems for each building. However, Alternative 2 is designed here as leaving the buildings connected the way that they are already connected (buildings 1, 2 and 3 in Figure 32). This means that their wastewater is treated jointly, while the wastewater from other buildings is taken care of individually.

Because leach fields allow water to infiltrate into the ground (Figure 31), no productive reuse of such water is possible. Therefore, onsite treatment and disposal are combined in Alternative 2. The dimensions can be applied to the wet source separation or mixed wastewater approaches. Sand filters would be the other option if reuse of treated wastewater were preferred. Sand filters also use the same design as leach fields except that there is collection of the wastewater. (See *6.5.1. Sand filter.*) Thus, the dimensions in this section can be applied to sand filters.

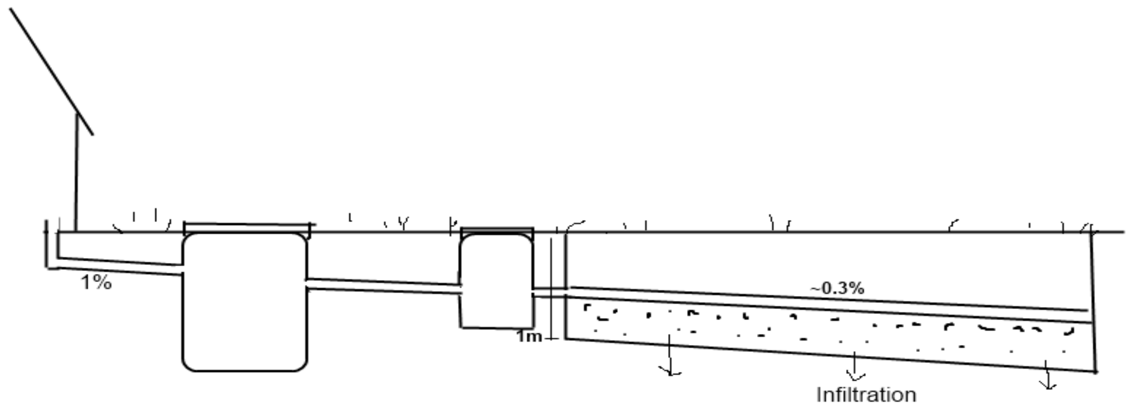

Figure 31. Schematic overview of wastewater management, Alternative 2.

8.2.1. Onsite treatment, disposal

The soil in the area around the current soak pit for the eastern buildings is not suitable for a leach field for large quantities of water (see *5.2. Physical conditions)*. Therefore a *reinforced leach field* is necessary, using extra material with a higher hydraulic conductivity. The following design is based on Swedish norm as described in a manual for small-scale domestic wastewater management by Naturvårdsverket (2003).

The dimensions of the area are the same as for a normal leach field. So the calculations for the three eastern buildings and an average household follow, using the same dimensioning criteria as mentioned in *6.6.4. Leach field*. The physical conditions make it suitable to apply zone B and a hydraulic capacity 30 l/m^2 (Figure 24). If the sand is well sorted, this leaves some hydraulic margin.

THREE EASTERN BUILDINGS

The three eastern buildings that are already connected have a daily flow of about 1600 l/day. (2 households+ cafeteria+ office)

Area needed = $\frac{1600\ \text{l/day}}{30\ \text{l}/m^2}$ = 53 m^2

For good distribution of wastewater throughout the length of the pipe without the help of a pump, the pipe should be less than 15 m long. If a length of 13.5 meters is selected, then 4 pipes each covering an area of 13.5 m^2 of reinforced material should suffice to take care of the hydraulic load. See Figure 32 for possible placement of the reinforced leach field.

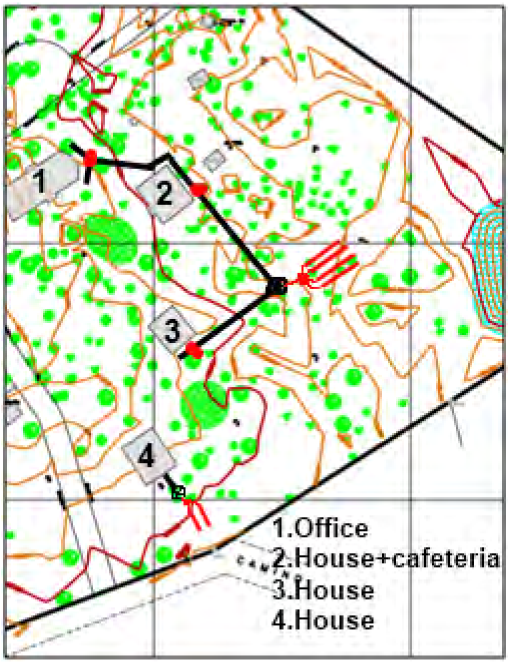

Figure 32. Present sewer (in black) and possible leach field placement (in red) combined for three buildings (Source: Modified from Ceasip (2008)).

AVERAGE HOUSEHOLD

The area needed for an average household in "better" hydraulic conditions is approximately 12 m^2 (as mentioned in *5.2. Physical conditions*). The area could be divided up into 2 pipes each with a length of 6 meters (see building 4 in Figure 32).

Other criteria (according to Naturvårdsverket (2003)):

- The ditches for the pipes should be well spaced to increase the area available for treatment.
- The gradient for pipes leading from household to the septic tank should be at least 10‰ (1 cm per meter).
- Pipes for leach field should have inner diameter >80mm.
- The collection/distribution chamber should have a diameter of <400mm for 2 distribution pipes. For the bigger leach field with 4 distribution pipes, use 600mm with depth 1 m.
- The gradient after the collection chamber throughout the length of the leaching pipes should be at least 3‰ when *no* pumps are used.
- Filtering sand should have size <8 mm.
- Depth from bottom layer to ground water table >1 m.
- Depths of layers are given in Figure 33 below.

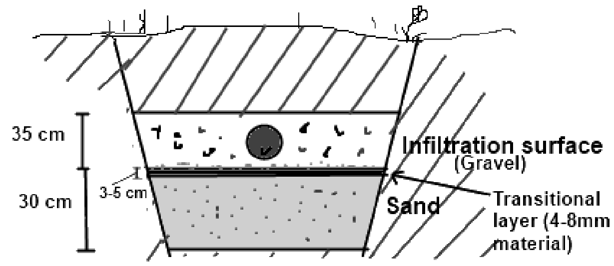

Figure 33. Layer depths for reinforced leach fields, reasonable total depth of about 1 m (Authors's figure inspired by Naturvårdsverket (2003)).

8.3. ECONOMY/BUDGET

The investment cost for starting up the mentioned systems according to Wet source separation is calculated roughly according to a Bolivian magazine guide *Presupuesta & Construcción* (2011) for construction work and budgets. An approximate budget of investment costs including materials and labor can be found in Appendix 6. Alternative 1 amounts to an approximate investment of 82 000 Bs but also has a potential material gain (in water and fertilizer saved) of 41 000 Bs. Alternative 2 amounts to an approximate 74 000 Bs with no potential gain. The mentioned budget for Alternative 1 includes all four eastern buildings while the budget for Alternative 2 only includes three eastern buildings. This is because one of the households, "Casa Director Técnico" (building 4), already has a septic tank and leaching system, so rather than building a new system the current system may only require maintenance. Otherwise, operation and maintenance costs for the suggested systems should be low if the systems are well constructed since they are simple and robust.

9. DISCUSSION

Alternative 1 fulfills the prioritized sustainability criteria to a higher extent than Alternative 2. Alternative 1 also has potential for economic benefits by means of decreasing groundwater use, the need to buy fertilizers, as well as improving production, while Alternative 2 has potential to decrease the need to buy fertilizers (if urine is separated).

There are however, a few reasons that make Alternative 1 questionable as a better alternative. The wastewater flows are relatively small compared to crops' water needs and there are extra costs and hassles associated with establishing irrigation with this water. Also, even if the ponds are well designed, they may cause problems with insects since open surface water can become their breeding ground. At Ceasip, an increase of insects may be marginal or insignificant considering that the treatment pond placement would be close to an already existing lagoon of a much larger size.

The availability of materials plays a central role in the decision-making of which technologies to implement. Among the more specialized technologies like wet eco-toilets, the availability is not obvious. Wet eco-toilets, like those sold by Wostman Ecology AB, can be exported from Europe to Bolivia although this is neither an economic nor practical solution. There is a company called Gandi in Cochabamba, Bolivia, that produces eco-toilets. They could also possibly produce wet eco-toilets. To determine these possibilities, this matter would require more involvement and research. Regarding the different technology options for onsite treatment, leach fields, sand filters and wetlands, have similar treatment efficiencies. Therefore, the choice of leach field or sand filter rather than wetlands could be motivated by the availability and costs of materials such as sand, and the desired use or disposal of the treated wastewater. Finer filtering materials such as sand allows for greater removal of nutrients from the wastewater through physical and chemical adsorption. If the wastewater is to be reused for cultivation, high nutrient removal is not necessary.

Socio-cultural aspects in this thesis may not be fully representative on a larger scale because of the casual nature of the social investigation. Regarding accuracy of values in the thesis, I consider most values to be representative though approximate. Because of the limited study time in fieldwork, I judged it to be of greater importance to get an idea of the big picture and approximate flows for the whole farm rather than focus on all the details. Since the amounts of urine that would be collectable from urine separation are rather uncertain, more precise calculations for sizes of the areas that could be potentially fertilized by urine are hardly possible at this point.

Since Ceasip is located in peri-urban Santa Cruz where central water and sanitation services may arrive within a number of years, this may also be an important aspect to consider while planning wastewater management. Drinking water services have already reached areas close to the farm and sanitation services may arrive to the areas within 15 years. The potential future connections to a central sewer and treatment could be regarded as another option for Ceasip. There is much uncertainty however, and 15 years is a long time span for not taking action towards acquiring proper wastewater management considering the already dire groundwater situation.

9.1. OTHER RECOMMENDATIONS

In the using of human excreta and/or wastewater for crops, proper health management is required regarding the following aspects: treatment, crop restriction, wastewater irrigation method and human exposure control. A multi-barrier pathogen reduction management is useful to avoid the risk of transmitting diseases by the fecal-oral route for all persons using toilets, persons possibly handling the excrement and wastewater, and the potential consumers of wastewater irrigated produce. The recommendations are listed in the *Guidelines for the safe use of wastewater, excreta and greywater* (2006).

Some toilets on the farm are already so old that they need to be exchanged soon. I recommend that only urine separation toilets be installed when toilets are changed. If wet eco-toilets are installed while some ordinary flush toilets still exist, perhaps wet eco-toilets will not be used. Consider trying a "reward system" where the users feel motivated to try the new toilets because of a reward involved.

9.2. FUTURE CONSIDERATIONS, DRY SOURCE SEPARATION

If eco-toilets are to be installed in the future at Ceasip, designs and dimensions of eco-toilets and collection/storage units that are technically functional in Bolivia can be found in reports by Agua Tuya (2008). Approximately 1.4 liters urine per day (Agua Tuya, 2008, s. 46) is excreted per average Bolivian. The amount of feces produced by an average Bolivian person is assumed to be 50 liters per year. If a dry eco-toilet system is installed in the future, feces can be dehydrated and sanitized then applied as soil amendment as described in *6. Review of relevant technology.* Considering that there is already windrow-composting piles at Ceasip, feces could also be mixed with the other compost for further sanitization. Materials and expert laborer for construction of eco-toilets can be found locally.

9.3. WATER AND WASTEWATER MANAGEMENT IN THE DIFFERENT FARM SECTORS

Other households: The other households that are not included in the eastern buildings do not pose such acute environmental risks to the groundwater in comparison since they have shallow leaching systems with lesser water quantities. More controlled treatment would of course be preferable. The Dry source separation is best from the sustainability standpoint. But if Wet source separation or Mixed wastewater is used, after a septic tank, horizontal flow sand filters give the opportunity for such control. The effluent could then be collected and distributed through a plant bed of a small-scale crop. (See Figure 34.) This would allow for specific investigations to be made on effects of wastewater on different crops. One possibility is to combine crop soil with *biochar*, a charcoal created through pyrolysis of biomass (Chan et al., 2007). Biochar is stable and carbon-rich. Due to its water retaining and soil amending properties, it can increase soil fertility, raise agricultural productivity and reduce pressure on forests.

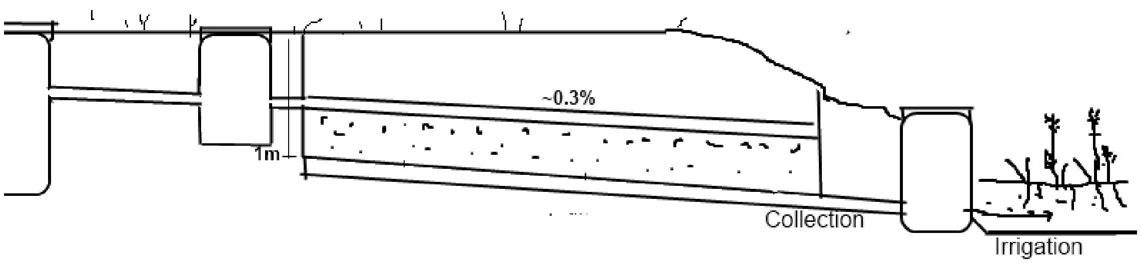

Figure 34. Individual household wastewater treatment possibility.

Dairy factory: Considering the extreme concentrations of grease, solids and BOD in the factory wastewater, it is essential to use technology that focuses on the reduction of these parameters. An anaerobic biogas reactor could be a beneficial treatment option because of the production of biogas; however, such a treatment may not suitable in the current farm conditions because of its technical complexity and need for maintenance to achieve good function. In addition, the low pH of this wastewater makes it likely that foul odors will be released during treatment due to sulphides. In that case, this could be remedied by the addition of lime to raise pH or by providing the conditions for oxidation.

Another less technical solution is as follows: First, a grease trap should be installed with a retention time long enough to allow the water to cool and allow the grease to float to the top and separate out (but not long enough to allow for settling). This will allow for simple and regular maintenance to remove grease and scum. Next, a settling of solids and a high-rate anaerobic digestion in an anaerobic reactor should be provided. A baffled reactor is a suitable option considering its efficiency and robustness (*6.6.3. Anaerobic reactors)*. Anaerobic digestion will decrease the amount of sludge produced. An aerobic step should also be considered to further reduce BOD and N and reduce potential bad odors before discharge. This could be achieved by collecting the wastewater in a chamber that releases the water upon reaching a certain level and taking advantage of differences in slopes, then allow the water to percolate though a sand filter before finally discharging. Design and dimensioning calculations can be found in for example *Decentralized Wastewater Treatment in Developing Countries* (Sasse, 1998, ss. 93-95). Regular maintenance will be required including desludging of the anaerobic reactor.

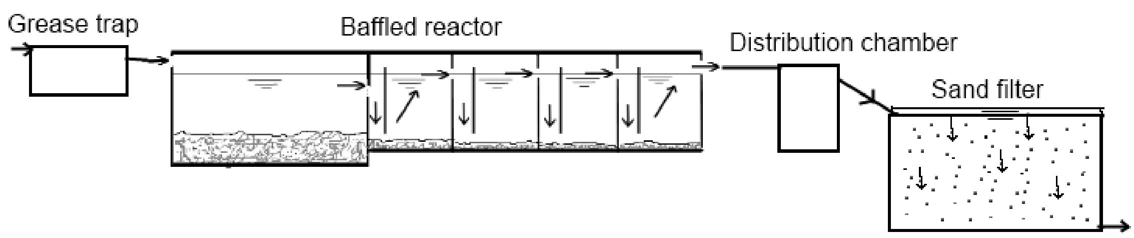

Figure 35. Overview of treatment possibility for Dairy factory, includes anaerobic and aerobic processes.

Stable: The stable wastewater can be pumped into a cistern or tankwagon (Figure 22) and transported to crops, rather than pumped out to the neighboring field. Alternatively, irrigation channels and production could be better planned for the neighboring field so that wastewater better benefits crops. Because of manure already being treated separately, results showed that wastewater was not overloaded with solids. The future location of the stable might make it possible to implement surface water irrigation or to combine wastewater treatment for the stable with the suggested the Alternative 1: pond treatment + irrigation. The possible risks of the cleaning/disinfecting chemicals should be considered.

Animal drinking water: When there had been water remaining in the cistern after filling water troughs in the fields, there was an observed tipping of "excess" cistern water onto the road during several occasions. These were sometimes large volumes of water. To prevent such wasting/tipping some training or education could be implemented and the need for tipping could be remedied by incorporating water-retaining materials into roads.

Fruit and vegetable gardens, fields: Irrigation with wastewater and application of excreta fertilizers could aid the gardens and fields to become more productive while preserving the fragile soils. (See *5.1.5 Fruit and vegetable garden, fields.)*

Groundwater, distribution net and water receptors: Drinking water: The drinking water and distribution net may need a temporary disinfecting to remove coliforms. Chlorine may be used in cases of high risk, but permanent use of chlorine should be avoided due to its harmful effects also on the helpful and purifying bacteria and protozoans (Sasse, 1998). Some pipes in the distribution net are in very poor shape. They may need to be exchanged in the near future to avoid leakage and water spills. Water meters should continue to be monitored on a regular basis, at least monthly, to check that there is no extraordinary wasting of groundwater.

9.4. REMAINING CHALLENGES AND POSSIBILITIES FOR CONTINUED WORK AND RESEARCH

I highly recommend Ceasip farm to continue developing environmental projects. Some projects can and should be continued and monitored simply by the employees, while others require more investigation that could be continued by receiving more university students. A list of suggestions is as follows:

- Implement modifications of wastewater management system.
- Realize training of employees in correct usage of user interface.
- Realize training of employees in proper maintenance and handling.
- Design and implement irrigation for use with wastewater and possibly surface water: the necessary pressures, appropriate pumps, frequency of watering, etc.
- Investigate slopes and other physical conditions from the planned future buildings to potential wastewater treatment and disposal/reuse areas.
- Investigate irrigation possibilities of fields farther from away from the current well and distribution net.
- Water flow research:
  - Continue monitoring of water meters on farm to control water usage and confirm data.
  - Investigate potential flow differences after farm activity expansions.
- Water quality research:
  - "Upstream chemical study," Avoid contaminating water with chemicals that may be harmful to microbes since the microbes are necessary for successful treatment. Contaminants to avoid in graywater: paint, toxics, solvents, disinfectants, medicines, etc. Optimize use of detergents, soaps

etc. Study of surfactants, and effects of upstream products in treatment. Eco-friendly replacement chemicals like for triclosan and chlorine products.
    - The sodium absorption ratio (SAR) of the wastewater was not analyzed in the study, but may be an important parameter to take into consideration. For safe irrigation, the SAR should be less than 18. (Mara, 2004)
    - Follow-up on treatment efficiency by checking effluent qualities in various points.
- Carry out water balance studies of the lagoons and wastewater treatment ponds, like the extent of the effect of stormwater, rainwater, evaporation, seepage, runoff etc. on the water levels.
- Investigate rainwater harvesting possibilities and improvements (like better lagoon storage).
- Investigate possibilities of "in-home" water recycling.
- Investigate the possibilities of preventing flooding of certain farm areas during heavy rains.
- Investigate and experiment with water-saving cultivation techniques, like through incorporation of biochar into Ceasip soils to improve qualities like water retaining.
- Investigate the possibility of using sludge from septic tanks/anaerobic reactors on crops.

10. CONCLUSIONS

The Ceasip farm has a property and activities that open up many opportunities to set a good example for peri-urban Santa Cruz by contributing to sustainable development through improved wastewater management. Results confirm that groundwater contamination is a problem and that there continued contamination is an ongoing risk unless specific preventive actions are taken.

- Water flow measurements at Ceasip showed the following:
  - Largest water flows used during two months were in the fruit and vegetable garden, with a water usage of about 600 m^3 per month or 70% of the total water usage.
  - The Ceasip buildings used together about 180 m^3 of groundwater per month or 20% of the total water usage.

- Nitrogen flows at Ceasip were found to be highest for the dairy factory wastewater and followed closely by domestic wastewater at around 70 kg/year.

Two design suggestions were found suitable for Ceasip to improve sustainability of wastewater management. The treatment and disposal suggestions are treatment ponds plus irrigation, sand filters or leach fields. Through implementation of treatment ponds plus irrigation, groundwater can be protected, groundwater use can be reduced and nutrients can be recycled, thus fulfilling the prioritized sustainability criteria. Sand filters and leach fields also fulfill these sustainability criteria, but to a lesser extent, while considering other potential problems like insects. Wastewater management could contribute to the prioritized sustainability criteria as follows:

- Protection of groundwater
  - Replacement of soak pit for suitable treatment prevents untreated wastewater from entering rapidly into the groundwater.
  - Wastewater treatment improves water quality before discharge.
  - Irrigation would allow vegetation to take up treated wastewater to further protect groundwater.

- Reduction of groundwater usage
  - Reusing wastewater from the four eastern buildings as irrigation water can reduce water usage. It would cover 10-33% of the water need in present conditions of the fruit and vegetable gardens, depending on the season.

- Recycling of nutrients
  - Urine separation gives the opportunity for controlled recycling of nutrients. Urine separation from all the domestic wastewaters at Ceasip could cover their fertilizer need of approximately 0.7-4.4 ha per year considering N and P, and depending on the type of crop cultivated.

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APPENDIX 1. RELATED PROJECTS IN BOLIVIA

Water and sanitation projects have been undertaken by many NGOs and organizations in Bolivia. According to a report by Water for People (2011), the successfulness of the projects relies on recognizing and developing the benefits of the water and sanitation systems combined with sufficient social education and training. Benefits include improved hygiene and health as well as economic gains. When properly managed, the fertilizer generated from a sanitation facility can be of high value. A successful example of such is of the municipality of Cuchumuela where mushrooms are grown under a certain type of pine tree, the production can be increased and generate larger income for the inhabitants when the pine trees are fertilized.

There are also examples of less successful sanitation projects. A sanitation project sponsored by the municipality and NGOs (including a local NGO, INCADE), was started in Saveedra, a small town slightly north of Santa Cruz de la Sierra. According to Adriana Burela (2011), the director of INCADE, most toilets were installed and put into use, but before the training was complete, the municipality withdrew its economic support. The service chain, like sales or use of fertilizer, was not closed. Currently many of the toilets lack maintenance, as in Figure 36, while many others have been exchanged for flushing toilets with septic tanks. However, to see to what extent the toilets are still being or *not* being used, an extensive study would be necessary.


Figure 36. Toilets in Saveedra lacking in maintenance. Left photo shows toilet with broken door and right photo shows a dirty, broken toilet ring.

However, projects with greater potential for success are ongoing. NGOs working on improvements in the regions of Cochabamba and Santa Cruz include Agua Tuya Foundation and Water for People. Especially around the region of Cochabamba, there have been a number of composting toilet projects where support still continues and water treatment plants such as constructed wetlands and graywater filters have been built and put into use. Some conclusions drawn from these projects showed that the greatest limiting factors are the risks related to the social and cultural aspects, like training, rather than technical problems. (Agua Tuya, 2008)

Field studies have been conducted in Cochabamba, Bolivia, years 2007 by Uppsala University students (Spångberg & Söderblom, 2008) and 2009 by Lund University students (Cordesius & Hedström, 2009). The efficiency of some constructed wetlands was evaluated and the feasibility of using constructed wetlands for wastewater treatment. Both studies concluding that several parameters were significantly reduced, but nutrients were not removed. Also, because of the high coliform bacteria concentration still remaining in the effluent, unrestricted reuse of the treated wastewater was not recommended. Constructed wetlands were however deemed to be a good treatment option for the climate and terrain conditions of Cochabamba and suitable for sparsely populated and poor areas since they require little energy, construction material and maintenance.

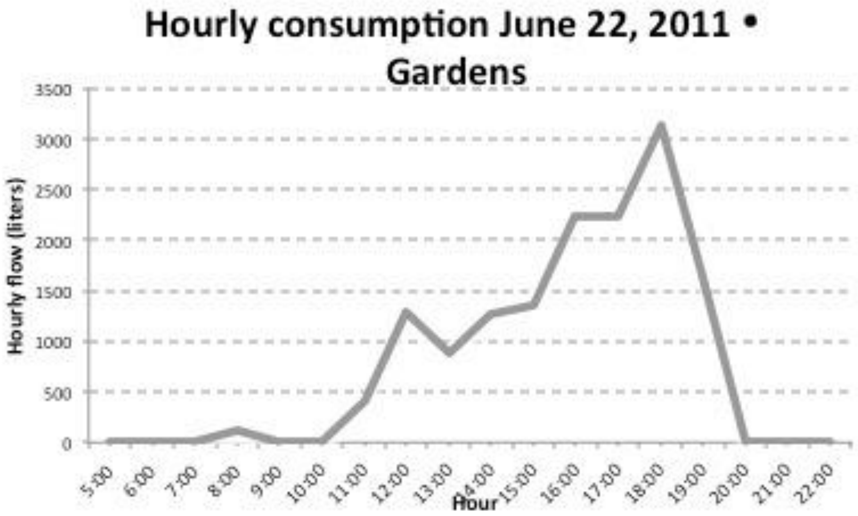
APPENDIX 2. WATER "LOSSES"

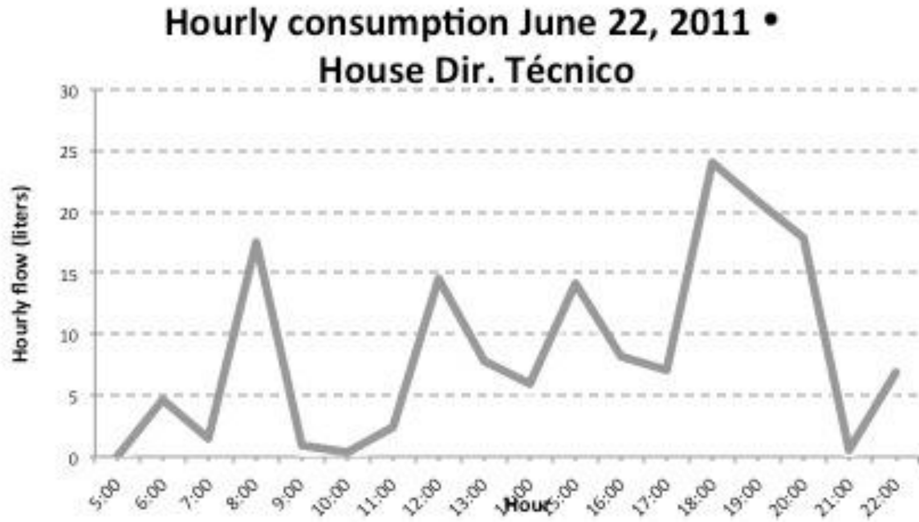
Water Loss Categorys/ Categorías	Water meter nr/ Medidor nr	Specifics/Specifico	Quantity/ Cantidad	Total Flows/Caudal (m3)	Total Flows/Caudal (m3)	Explanation, Dimensions/dimensiones
				May/Mayo	June/Junio	
Irrigation/Riego	1	Fruit n Veg Garden/Huerta		**563**	**422**	Water meter/medidor
		Lawns/Jardín (de oficina):				
	part of 3	Casa Director		**0**	**42**	Difference between actual total and total without irrigation/Diferencia entre total actual y total sin riego
		Bomba y tanque separado		**25**	**25**	Approx 5 days@ 5m^3 (Podría ser mas)
		Field/Pasto cerca del Establo		**10**	**50**	Approx 10 days@ 5m^3
		Field/Pasto entre Casa DirTec y Taller		**0**	**57**	Difference between actual total and total without irrigation/Diferencia entre total actual y total sin riego
	part of 7	Lawns/Césped fuera de quesería		0	**18**	Difference between actual total and total without irrigation/Diferencia entre total actual y total sin riego
		TOTAL IRRIGATION/ RIEGO		**598**	**596**	
Water troughs/ Agua bebederos		Outside/Fuera:				
		Bebedero grande1	7	**17**	**17**	7 changes per month/ 7 cambios por mes; d=2.5m, h= 0.5m; 50% tossed/botado
		Bebedero grande2	7	**13**	**13**	d=2.2m, h= 0.5m; 50% tossed/botado
		Bebedero grande3	7	**7**	**7**	d=1.65m, h= 0.5m;50% tossed/botado
		Bebederos potreros	49	**25**	**25**	Volume for partly filled horizontal cylinder-->520 l; V=l*[r^2*cos^-1((r-h/r)-(R-h)*(2rh-h^2)^0.5]; d=0.6, l=2.94m, 63% full; 7days*7 troughs;50% tossed/botado
		Botado de cisterna		**7**	**0**	Estimated from observations, Not observed in June/No observado en Junio
		Stable/Establo:				
		Compartamientos (terneros)	180	**2**	**2**	6 calves*31days resp 30 days@24 liters/6 terneros*31days resp 30 días@24 litros; 50% spilled/botado
		TOTAL TROUGHS/BEBEDEROS		**73**	**66**	
Washing of vehicles/Lavados de vehiculos	part of 6	Workshop/Tallér	4	**2**	**2**	4 Saturdays, approx from days with high consumption minus normal days/ 4 Sábados, estimación de los días con alto consumo-días normales
		Old building/Casona	1	**0**	**1**	1 time
		TOTAL VEHICAL WASHING		**2**	**3**	
Open taps/ Grifos abiertos	part of 8	Sports field/Campo de fútbol		**5**	**0**	Not observed in June/No observado en Junio
Cleaning/ Limpieza	various	Various/Porches, botas, suelos, etc	20	**1**	**1**	Approx 20 days/Estimación 20 días

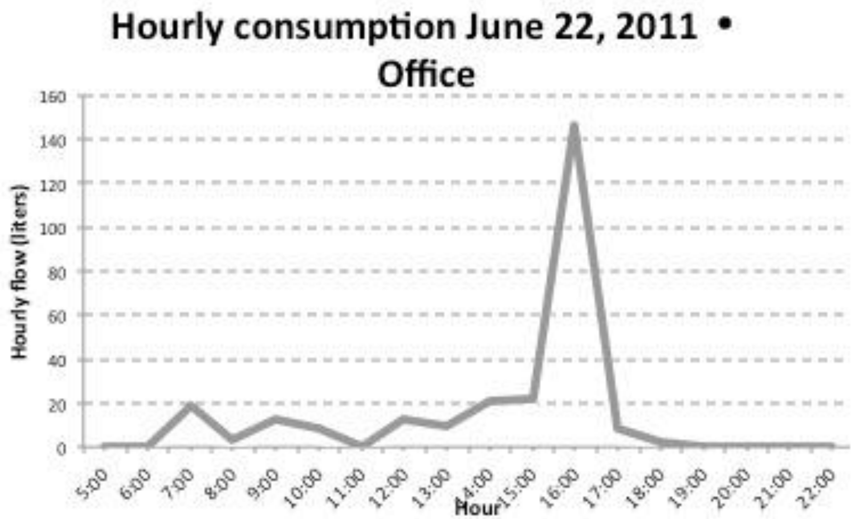
APPENDIX 3. WATER FLOWS, COLLECTED WASTEWATER

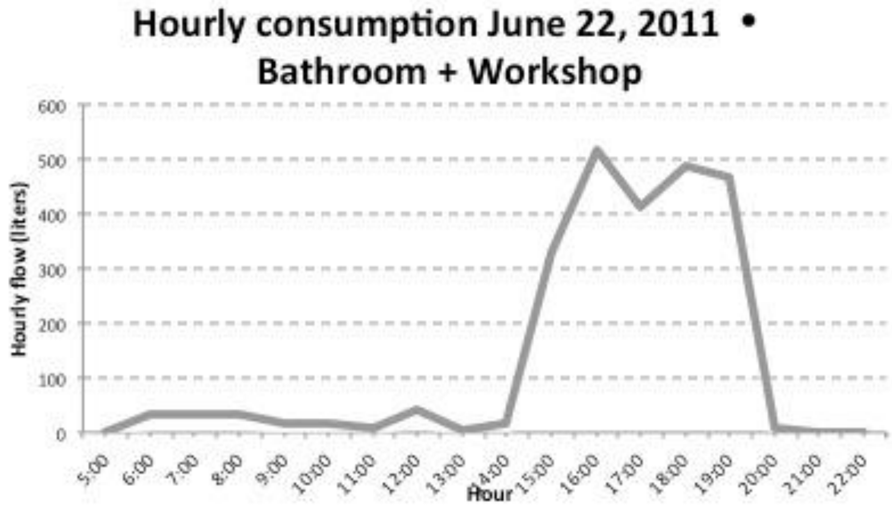
Water Meter nr	Wastewater source	Water Consumption (m3) May (m3)	Water Consumption (m3) June (m3)	Consumption minus IRRIGATION (m3) June (m3)	Consumption minus IRRIGATION (m3) Average monthly	COLLECTED WASTEWATER (m3) Average monthly	COLLECTED WASTEWATER (liters) Average daily	Explanation
2	Office/Oficina	26	11	11	19	**17**	**540**	From water meter. Sometimes water is used for cleaning etc. Assume 90% collection.
3	House + Cafeteria/Casa Director + Cafeteria	25	61	19	22	**20**	**639**	Water meter includes lawn irrigation. Otherwise, assume 90% collection. House includes washing machine.
4	House/Casa Huespedes	5	6	6	5	**5**	**160**	Water meter. Alost all water collected. Assume 95%.
5	House/Casa Director Técnico	10	9	9	10	**9**	**279**	Water meter. Assume 90% collection.
6	Bathroom + Workshop/Baño de casona + Tallér	13	83	26	20	**18**	**571**	Water meter includes mech workshop tap and field irrigation. Assume 90% collection after subtracting irrigation.
8	House/Casa Juan Carlos	20	13	13	17	**15**	**485**	Water meter includes bathroom used by employees. Assume 90% collection.
	House/Casa de Milanio:	20	20	20	20	**18**	**581**	(guessed- more people in house, more visitors, high value). Assume 90% collection.
	(Separate bathroom, washstation, kitchen)/(Baño,Estación de lavado,Cocina)							
7	Dairy Factory/Quesería	9	28	9	9	**9**	**284**	Assume that 95% is collected.
	Stable/Establo:							
	Farmacia y Compartamientos	5	5	5	5	**5**	**145**	Guessed from washing of drinking buckets. Asumir recolección de 90%.
	Lechería (PURÍN)	50	50	50	50	**45**	**1456**	Guess of 10% loss in Evaporation etc
	TOTALS	**184**	**286**	**168**	**176**	**159**	**5139**	

APPENDIX 4. HOURLY WATER USAGE FLOWS

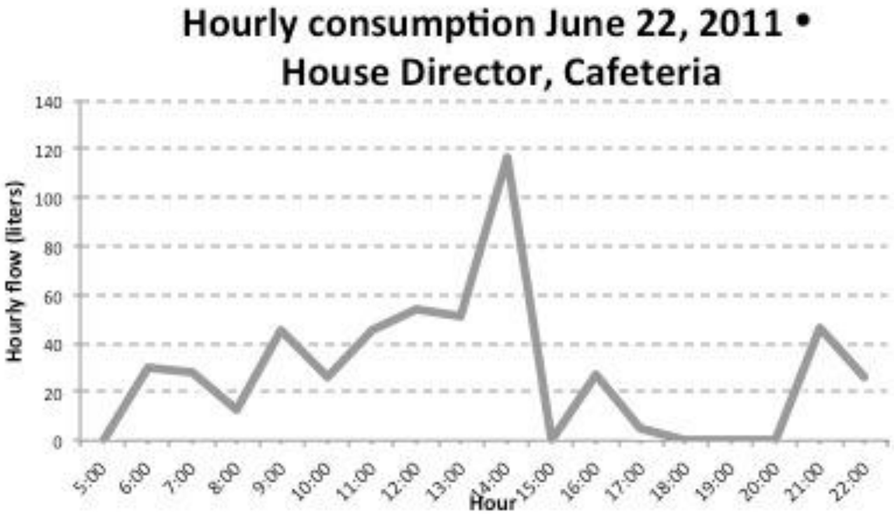


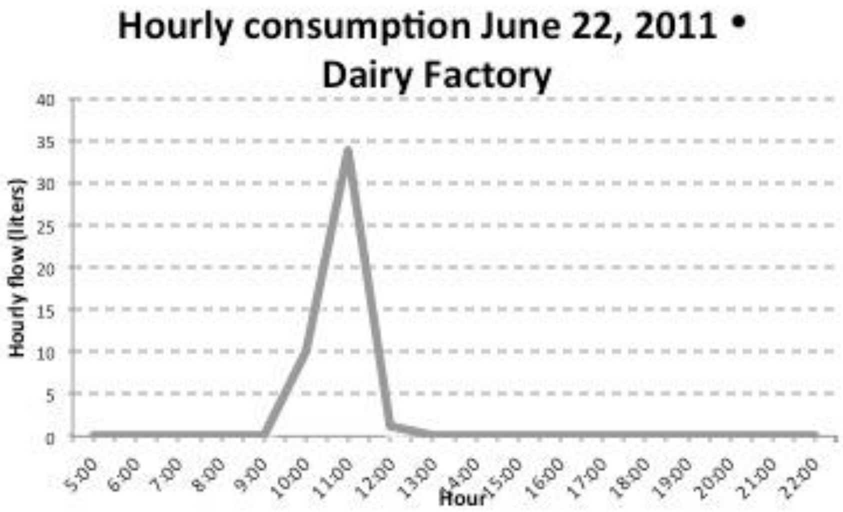


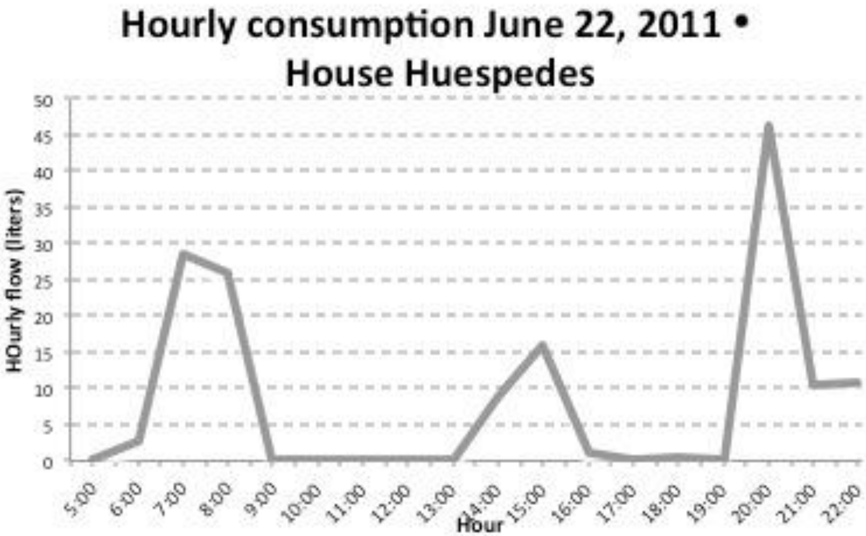


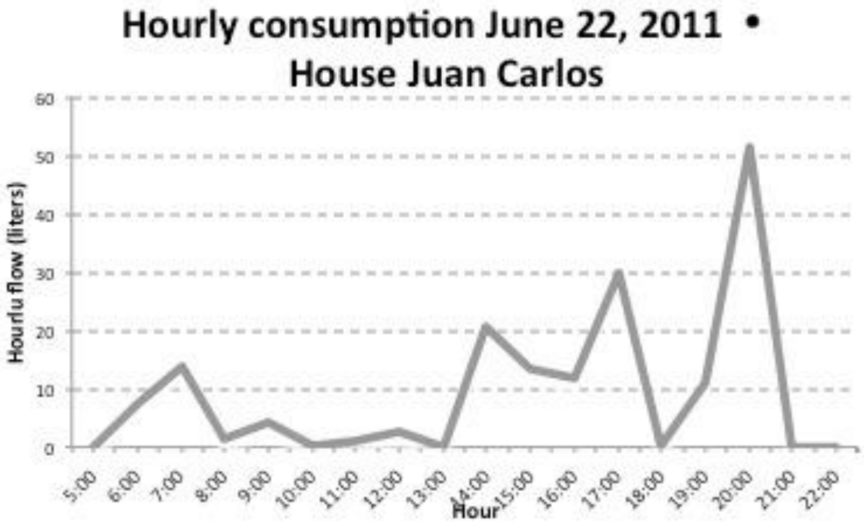


Appendix 4 (continued).Hourly water usage flows









APPENDIX 5. WATER QUALITY RESULTS

Table A5.1. Wastewater quality 2011- Domestic wastewaters (Results from UTALAB, Santa Cruz)

WW source:		**Office, Cafeteria, Casa Director, Casa Huespedes**				**Casa DirTécnico**		**Casa Juan Carlos**			**"Mid" bathroom**
Dates:		**May 24**		**June 24**		**May 24**	**June 24**	**May 24**		**June 24**	**May 24**
Duplicates:		**A1; A2**	**B**	**A**	**B**	**A1; A2**		**A1; A2**	**B**		
Parameter	**Units**										
Temp*	*C	25.2		23.1		27.2	23.4	26.4		23.4	28.6
pH		6.43		6.19		7.7		7.18			6.94
Cond*	µS/cm	641		679		1568	1524	1000		1067	387
DO*	mg/l	6.5				1.4		8			0.9
Fec Coliforms	MPN/100ml	4.30E+06				4.30E+03		9.30E+05			
BOD_5	mg/l	262.5	258	350		70		65	90		50
COD	mg/l			627							
Greases	mg/l	27.2		29.6		10.4					
Total P	mg/l	2.32**	2.82**	2.4**		2.16**		2.58**	2.8**		1.55**
Total N	mg/l	<5**; 8.1**	3.95E+01	<5**	6.4	135.5; 87.6	<5**	<5**; 96,3	93	5**	<5**
NH_4^+-N	mg/l	38.2		32.5			110.02	107		88.01	
TDS	mg/l	371									
TSS	mg/l	64		83		66					
As	ppm	<0.002									
Cd	mg/l	<0.02									
Hg	mg/l	<0.001									
Pb	mg/l	<0.1									

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

Note: A1 and A2 are repetitions of the total N of the same samples

Table A5.2. Wastewater quality 2011- Non-Domestic wastewaters (Results from UTALAB, Santa Cruz)

WW source:		**Dairy factory**		**Stable**
Dates:		**May 24**	**June 24**	**May 24**
Duplicates:		**A1; A2**		
Parameter	**Units**			
Temp*	*C	27.7	23.5	28.1
pH		4.09	3.96	6.52
Cond*	µS/cm	6230	8060	479
DO*	mg/l	0.6		8
Fec Coliforms	NMP/100ml			9.30E+06
BOD_5	mg/l	455**	4700	103
COD	mg/l		19950	
Greases	mg/l	11825	2610.8	
Total P	mg/l	2.74**	1.5**	2.3**
Total N	mg/l	2030; 1688	215.6	<5**
NH_4^+-N	mg/l		20.9	17.96
TDS	mg/l			
TSS	mg/l	35778		71
As	ppm			
Cd	mg/l	<0.02		
Hg	mg/l			
Pb	mg/l	<0.1		

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

Note: A1 and A2 are repetitions of the total N of the same samples

Table A5.3. Water quality 2011- Ground waters (Results from UTALAB, Santa Cruz)

W source:		Tap water(Casa Huesp.)		New deep well (direct)	Old shallow well
Dates:		May 24	July 2	May 24	May 24
Duplicates:					
Parameter	**Units**				
Temp*	*C	26.6	16.6		24.9
pH		7.76	7.7*		7.29
Cond*	µS/cm	70.3	68.6		851
DO*	mg/l	6	7.3		2.9
Alcalinity (CaCO3)	mg/l	34			
Fec coliform	NMP/100ml	<2.00E+00		<2.00E+00	9.30E+05
Tot Coliform	NMP/100ml	2.70E+01		2.00E+00	9.30E+05
Total P	mg/l				0.51**
NH_4^+-N	mg/l				<0.02
NO_3^-	mg/l	2.8			
TDS	mg/l	81			
Total Fe	mg/l	0.33			
Manganese	mg/l	<0.02			
As	ppm				<0.002
Cd	mg/l				<0.02
Pb	mg/l				0.2

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

*** after rainy days, approx 34 mm in 3 days

Note: A1 and A2 are repetitions of the total N of the same samples

Table A5.4. Water quality 2011- Surface waters (Results from UTALAB, Santa Cruz)

W source:		**N.East lagoon (Large)**			**S.West lagoon (Workshop)**	
Dates:		**May 24**	**June 13**	**July 2**	**May 24**	**June 13**
Duplicates:		**A1;A2**		*******		
Parameter	**Units**					
Temp*	*C	28.15	23.9	16.3	25.5	21.8
pH		5.96	6.7*	7.2*	7.07	7.2*
Cond*	µS/cm	89.1	81.7	85.1	263	304
DO*	mg/l	1.1	5	3.7	7.3	1.5
Fec Coliforms	MPN/100ml	9.10E+02			2.30E+03	
Greases	mg/l				<1	
Total P	mg/l	0.25**			0.53**	
Total N	mg/l	<5**;<5**			8.1	
Cd	mg/l	<0.02				
Pb	mg/l	<0.1				

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

*** after rainy days, approx 34 mm in 3 days

Note: A1 and A2 are repetitions of the total N of the same samples

Table A5.5. Water quality 2011-Quality control (Results from UTALAB, Santa Cruz)

W source:		**Destilled water**	**Known P conc of 5 mg/l**	**Conduct control, Office etc**		**Conduct control, Dairy factory**	
Dates:		**May 24**	**May 24**	**June 24**		**June 24**	
Duplicates:				**Insitu***	**lab**	**Insitu***	**lab**
Parameter	**Units**						
Fec coliform	NMP/100ml	<2.00E+00					
Tot Coliform	NMP/100ml	<2.00E+00					
Cond	µS/cm			679*	731	8060*	8800
Total P	mg/l		1.03**				

*insitu

** especially unreliable data (see *5.3 Data accuracy)*

APPENDIX 6. BUDGETS FOR TWO SYSTEM ALTERNATIVES

APPROXIMATE BUDGET FOR 4 EASTERN BUILDINGS, ALTERNATIVE 1: WW MANAGEMENT TREATMENT POND SYSTEM				
	Unit	**Unit cost (Bs.)**	**Quantity**	**Total cost (Bs.)**
Excavation (4 septic tanks)	m3	52.16	11	573.76
Excavation (5*2m3 urine tanks)	m3	52.16	10	521.6
Excavation (sewer)	m3			
modifications around current buildings		52.16	6	312.96
extension from current septic tank to treatment ponds		52.16	35	1825.6
new connection(casa Dir Tecnico)		52.16	39	2034.24
Excavation (ponds)	m3	52.16	31	1616.96
Plastic septic tank 2300l CARMEN PVC(material+labor&equipment)	piece	2552	3	7656
Holding tanks urine 1100l Tanque tricapa NUEVA ERA	piece	1897	6	11382
Sewer system				
pipes 4", approx 20 m	4 m	69.3	5	346.5
pipes 3"(solids-free), approx 240 m	4 m	47.9	60	2874
accessories	mixed			3000
Geomembrane imperm. plastic liner(material+installation)	m2			
facultative pond		92.27	34	3137.18
maturation pond		92.27	50	4613.5
storage pond		92.27	28	2583.56
Inlets/outlets, misc.	mixed			5000
Gandi (Cochabamba), urine separation toilet	piece	3500	10	35000
TOTAL INVESTMENT COST				**82477.86**

(Irrigation system costs not included)

Possible costs saved by reusing water	**Unit**	**Unit cost (Bs.)**	**Quantity (monthly)**	**Total monthly gain (Bs.)**
Water saved (Water price, domestic, Saguapac (Degadillo, 2011)	m3	2.5	48	120

Fertilizer (compared to locally sold, dry commercial NPK fertilizers) saved	kg	7.2	7.16	51.6
Total monthly gain				171.6
(Potential for production increase not included)				
TOTAL GAIN AFTER 20 YEARS (EXCLUDING INFLATION ETC.)				**41184**

APPOXIMATE BUDGET FOR EASTERN BUILDINGS, ALTERNATIVE 2. SAND FILTER/ LEACHING SYSTEM

	Unit	Unit cost (Bs.)	Quantity	Total cost (Bs.)
Excavation (4 septic tanks)	m3	52.16	11	573.76
Excavation (sewer)	m3			
modifications around current buildings		52.16	6	312.96
Excavation (big leach field)	m3	52.16	53	2764.48
Plastic septic tank 2300l CARMEN PVC(material+labor&equipment)	piece	2552	3	7656
Holding tanks urine 1100l Tanque tricapa NUEVA ERA	piece	1897	6	11382
Sewer system				
pipes 4", approx 20 m	4 m	69.3	5	346.5
pipes 3"(solids-free), approx 84 m	4 m	47.9	21	1005.9
accessories	mixed			3000
Leach system (large, for 3 buildings)				
Perforated pipes (54 m) 4"	4m	69.3	13.5	935.55
collection/distribution chamber	piece	317.2	1	317.2
gravel (53m2*0.35m=18.55m3)	m3	130	19	2470
sand(53m2*0.30m=15.9m3)	m3	130	16	2080
labor of filling/compacting earth 53m3	m3	32	53	1696
Inlets/outlets, misc.	mixed			5000
Gandi (Cochabamba), urine separation toilet	piece	3500	10	35000
TOTAL INVESTMENT COST				**74540.35**