BALANCING CONSUMPTION AND AVAILABILITY IN A MULTIPLE USES OF WATER SYSTEM

By

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Dedicatoria

A Dios por esta vida, llena de cosas mágicas, lindas, dolorosas, pero todas valiosas; por darme fuerza cada día y por las personas que ha puesto a mi lado para que me acompañen en este camino

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Certificate of authorship

I certify that:

(i) I am responsible for the work submitted in this project report, and that the original work is my own except as specified below.

(ii) I have not submitted this work to any other institution for the award of a degree

(iii) All field work and computer programming has been carried out by me with no outside assistance except as noted below:

I received assistance from Isabel Bolaños, Luisa Fernanda Suarez, Erick Brand, Danny Rendón and Arley Portilla to conduct interviews to the locals of *La Palma Tres Puertas*

I received assistance from Marie Luneau to transfer data from the questionnaires to an Excel spreadsheet

I received assistance from Marie Luneau to undertake domestic water consumption observations

I received assistance from Florentino Urrego to measure the water flow at the inlet of *La Palma Tres Puertas* storage tank

(iv) All information (including diagrams and tables) or other information which is copied from, or based on, the work of others has its source clearly acknowledged in the text at the place where it appears.

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Abbreviations and Acronyms

ACRU	Agricultural Catchments Research Unit
AQUASTAT	FAO's global information system on water and agriculture
BFP	Basin Focal Project
B-teeth	Brush teeth
CBWC	Crops Blue Water Consumption
Cenicafé	Centro Nacional de Investigaciones del Café
CFC	Crop Fumigation Consumption
CGIAR	Consultive Group on International Agricultural Research
CGWC	Crop Green Water Consumption
Cinara	Instituto de Investigación y Desarrollo en Agua Potable, Saneamiento Básico y Conservación de Recursos Hídricos, Colombia
COL$	Colombian Pesos
CPC	Coffee Processing Consumption
CPWF	Challenge Program on Water and Food
CPWF-MUS	Challenge Program on Water and Food – Multiple Use Water Services Project CP28
CROPWAT	FAO's model for deficit irrigation scheduling
DANE	Departamento Administrativo Nacional de Estadística de Colombia
DC	Domestic consumption
DFID	Department for International Development, UK
DNP	Departamento Nacional de Planeación, Colombia
DRA	Demand Responsive Approach
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information System
HH	Household
HYLUC	Hydrology Land Use Change Model
IDE	International Development Enterprises
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales, Colombia
IRC	International Water and Sanitation Centre, The Netherlands
IWMI	International Water Management Institute, Sri Lanka
kc	Crop coefficient
kg	Kilogram
Km	Kilometer
Kv	Volcanic outcrop
l	Liter

l/day/hh	Liter per day per household
l/He*month	Liter per Hectare per month
l/head*day	Liter per head per day
LANDSATTM	Landsat Thematic Mapper or Earth observation satellite with seven bands at 30m spatial resolution
lpcd	liter per capita per day
m	meter
m/period	meter per period
m^2	square meter
m^3	cubic meter
m^3/KgPC	cubic meter per kilogram of parchment coffee
m^3/m^2*period	cubic meter per square meter per period
MDGs	Millennium Development Goals
mm	millimeter
mm/yr	millimeter per year
MUS	Multiple-uses of water
PAAR	Programa de Abastecimiento de Agua Rural, Colombia
PFL	Pour Flush Latrine
UNDP	United Nations Development Program
RAS	Reglamento Técnico del Sector Agua Potable y Saneamiento Básico de Colombia
SLA	Sustainable Livelihoods Approach
SPC	Swimming Pool Consumption
ST	Septic Tank
SV	Sevilla Association
SWAP	Model for improving water productivity
UN	United Nations
UNEP	United Nations Environment Program
UNICEF	United Nations Children's Fund
US$	American Dollar
WEDC	Water, Engineering and Development Centre
W-hands	Washing-hands
WHO	World Health Organization

1 INTRODUCTION

1.1 Context

Colombia is located in the northwestern part of South America. The country occupies an area of 1,141,748 km^2, administratively divided into 32 departments and 3 special districts (AQUASTAT, 2000), and geographically divided in 5 main regions with strong different characteristics (Meisel, 2007). Figure 1-1 shows a map of Colombia and its location.

Figure 1-1 Colombia and its location *Source: World Bank (2010)*

Colombia has a total population estimated for 2010 as approximately 45 million (DANE, 2010). This population is diverse: some 60% are mixed Spanish/indigenous, 20% claim direct European descent, 18% are Afro-Colombian, and 2% are Indigenous. Population is unevenly distributed in space, 74% of the total population live in the Andean region occupying approximately 8% of the country area (Meisel, 2007). The Andean region contains the four main urban centres and some rural areas where over the past century the coffee economy had its peak (Murad, 2003).

Approximately, 33% of the country's area is mountainous; climate is mainly tropical with uniform temperatures, except for differences in altitude, which break this uniformity, leading to a hot (up to 1000 m), temperate (1000 - 2000 m) and cold climate (above 2000 m) (AQUASTAT, 2000). The geographical location, varied topography and climate regime has characterized Colombia as one of the territories with major water availability in the world. However, this availability is not homogeneously distributed between the different regions; some areas have large surpluses and others suffer deficits. Deficits occur where most population is concentrated and water yields present low values. The average annual per capita water supply for the driest year condition, and accounting for quality alteration is estimated at 26700 m^3. Water demand for 2006 was distributed as follows: agricultural sector 61%, domestic sector 21%, industrial sector 9%, livestock 3% and services 1% (IDEAM, 2008).

Colombia is classified as a middle-income country. Its main exports are petroleum, coffee, coal, emeralds, flowers and bananas (World Bank, 2010). Colombia estimated Gross Domestic Product at Purchasing Power Parity (GDP PPP) for 2007 was 8,587 US$ per capita (UNDP, 2009). Agriculture is a main activity within the economy due to its inclusion in agribusiness, foreign trade, employment generation and quality of life. However, the Agricultural GDP decreased from 25% in 1970 to 8.5% in 2008 (Gutiérrez, 2009). The Gini coefficient has remained stable from 2003 to 2009 by 0.59 (DNP, 2009). Therefore, inequality is high in Colombia and is one of the highest in Latin America (UNDP, 2009). Poverty and inequality are issues that remain as some of the country's main challenges (World Bank, 2010).

Rural Colombia

In Colombia, the rural population comprises small, medium and some large landowners, fishermen, artisans, those engaged in mining, Indians and many of the Afro-Colombian communities (Murad, 2003). While the rural population has declined in percentage terms from 33% in 1985 to 24% in 2010, the number of inhabitants in rural areas is still significant, estimated at about 11 million (DANE, 2010).

The most representative activities of the rural population are agriculture and livestock, despite the drop on the growth rates of the agricultural sector, particularly, the strongest decline in 1990 due to economic opening and the substantial reduction in coffee production due to the breakdown of the International Coffee Agreement and phytosanitary problems with this crop (Forero, J., 2010).

The agricultural sector crisis, the purchase of large areas of land by drug dealers, violence and forced displacement and the lack of investment in the sector have led to an unequal distribution of land - the Gini coefficient for land ownership in Colombia is 0.77 (Rodriguez, 2005). For example, in 1995, 47% of farms were under 5 Hectares and occupied 3.2% of the area, while 3% of farms over 200 hectares occupied 40% of the area. Many of these large farms are dedicated to extensive livestock, changing the previous rural economy and the traditional annual crops (Pérez & Pérez, 2002). As result, from 9 million hectares suitable for agriculture, only 5 million are used. On the contrary, from 19 million eligible for livestock, 40 million are used (Murad, 2003).

Rural areas in Colombia have much higher poverty than urban areas. While urban poverty was 30,7% and indigence 6,8% in the cities, for the same period, in rural areas poverty was 65,2% and indigence 32,6% (DANE & DNP; 2009). In terms of income, the richest 10% of the rural population receives 30 times the income of the poorest 10% and about 79% of the rural people do not get sufficient income for a minimal basket of satisfaction (Pérez & Pérez, 2002).

Water service provision in Colombia rural area

Along with the unequal distribution of land and income, access to water service is uneven in the rural area compared to the urban area. Since 1994, Colombia adopted a model of decentralization in the provision of public services, allowing private sector participation. However, ensuring service provision remains as State responsibility. The private sector operates especially in cities (Foster, V., 2005) while in the rural areas the service is provided by local communal organizations, since this market is usually not attractive for private providers. Consequently, rural services commonly present weak operational and financial indicators, and provide water of deficient quality. Hence, while in 2004 access to water was 93% in urban areas, in rural areas it was 71% (World Bank, 2004). This figure includes non-conventional options and does not take into account quality and continuity, thus, it is expected that the actual coverage is lower (Rojas, 2008).

Although, as discussed previously, smallholding occupies a minor part of the rural area, it remains important since in this small area most of the rural population is concentrated and have their livelihoods; about 73,4% of the rural homesteads in Colombia have agriculture or livestock activities (DANE, 2005). Those activities depend on the access to water. However, poor rural families have been traditionally excluded from land improvement programs and there is no agency responsible for providing water for those uses. The domestic sector is concentrated in drinking water supply and the land improvement sector has been weak and subject to various reforms in the past 20 years. Most investments in irrigation have been made by the private sector (AQUASTAT, 2000). Thus, Colombia contributes less than 3% of the irrigated land area in Latin America and this area corresponds to large landholdings, located on the flat areas and with soils of good quality that are destined for the cultivation of cash crops (Urrutia, 2006). In consequence, poor farmers that lives on sloping areas and develop subsistence agriculture rely mostly on water supply systems designed for domestic purposes.

The lack of recognition of the small scale productive uses within the mandates of the agencies that make up the water institutions in the country, domestic or irrigation sector, leads to ignore these uses in the planning process of water systems. It makes difficult for families to get their livelihoods and improve their food security.

The current practice for designing water supply systems in Colombia is established under the Basic Regulation for the Drinking Water and Sanitation Sector RAS – 2000 (Mindesarrollo, 2000), which indicates that in drinking water projects for "human consumption", the net allocation to satisfy "the basic water needs for one person", is based on the number of inhabitants in the settlement. It is lower for communities less than 2500 people (100 – 150 lpcd) and there is no upper limit for communities with more than 12500 people. These guidelines, although formulated for urban areas, have been traditionally used for rural communities. In 2007 a rural RAS was proposed (Minambiente et al., 2007), but it adopted the same criteria for the allocation and retains the purpose of systems for only human and domestic use (Dominguez et al., 2008).

This rigid regulation results in planning and practice that ignores real peoples´ needs. For instance, the PAAR - Phase I, a Rural Water Supply Program[1] developed from 2003 – 2006 to built water supply systems for rural areas in *Valle del Cauca* Department, worked in 128 communities, benefiting 138,000 people. This program had a level of recognition of the linkages between access to water and livelihoods, although, analysis on 92 interventions highlighted that small-scale productive activities at the household level were identified in 100% of the project sites (agriculture and livestock). However, 60% of designs were based still on the RAS - 2000 criteria and just 5% of the agreed Statutes for system management allowed to use water from the water supply system for productive uses (Cinara, 2007a). This case is an example of the lack of recognition of people´s livelihoods at all levels of the water institutions, with the long-term implications this may have on the sustainability of the systems and eventually on the perpetuation of rural poverty.

1.2 Background

The UN in 2000 established the Millennium Development Goals (MDGs). Three of them are significant to the water sector: *"to eradicate extreme poverty and hunger; to promote gender equality and empower woman; and to ensure environmental sustainability*" (UN 2006). On the other hand, in 2002, at the Johannesburg Declaration on Sustainable Development, participant countries agreed to speedily increase access to basic requirements including among others, clean water, sanitation, food security and protection of biodiversity (UN, 2002).

[1] *Programa de Abastecimiento de Agua Rural* for its Spanish accronym

Now, access to water for poor people is an important issue on the international agenda. After the Johannesburg Declaration, the concept of Multiple Uses of Water Systems (MUS) emerged as a strategy to introduce water access that responds to the full range of people needs: both domestic and productive, contributing to poverty alleviation and equity (MUS group, n.d.). In Colombia, dialogue between academics and water sector professionals began around the topic in 2003 at the International Conference: "Multiple uses of water for life and development" (Peña et al., 2006) and later in 2004 through the E – Conference on Multiple Uses of Water (IRC & Cinara, 2005). These spaces gave visibility to the issue of productive use of water, especially for rural water supply systems.

Following international trends on poverty reduction and access to water, the Colombian government proposed a strategy to reduce poverty and inequity (DNP, 2005), which includes various programs. Within this strategy, in 2007, the Ministry of Agriculture started a program to construct irrigation schemes in communities that have farmers associated in organizations incorporated to productive chains. However, people with small scale productive activities did not satisfy the requirements to get access to this program and in contrast, in 2009 it was strongly criticized, considered as a Policy to favour the rich instead to favour the poor (Cambio 2009; Semana 2009; Semanario Voz; 2009). Additionally, in 2007 the government launched the Policy of "Water Departamental Plans" which aimed to increase coverage and to improve the quality of drinking water services (DNP, 2007). While these Plans have as guidelines the effective inter-institutional coordination, and the need for integral approaches, these integral coordination and approaches are inside the traditional institutional water and sanitation sector, including just water for domestic demands, wastewater collection and treatment, and waste management. Thus, the agricultural and other important productive sectors for some rural areas, like Trade and Tourism, were out of the picture, and then the approach was again to look at the rural areas with the same criteria for the urban.

Between 2004 and 2009, funding by the Challenge Program on Water and Food (CPWF), an international research project was carried out focused on develop tools to promote MUS (CPWF-MUS project). Activities were carried out by a consortium consisted of the International Water Management Institute (IWMI), International Water and Sanitation Centre (IRC), and International Development Enterprises (IDE), and a wide range of national partners in 8 countries: Bolivia, Colombia, India, Nepal, South Africa, Zimbabwe, Thailand and Ethiopia. Fieldwork took place in 30 rural and peri-urban communities, districts or regions; and learning alliances[2] were forged for scaling up MUS. The national experiences were disseminated and discussed in global networks and forums (van Koppen & Smits, 2010).

[2] Defined by Lundy et al (2008) as follows: "*Process undertaken jointly by research organizations, donor and development agencies, policymakers and private businesses, which involves identifying, sharing and adapting good practices in research and development in specific contexts. These can then be used to strengthen*

Cinara undertook the research in Colombia where the focus was to create awareness about the importance of multiple uses of water for poor rural families, analyze legal and institutional frameworks for water provision, and formulate proposals to change those frameworks. These activities were developed following the same strategies of the international project.

Despite the progress made during CPWF-MUS on the conceptual understanding of the approach, it has been acknowledged the need to investigate how MUS can be applied in practice, and especially how multiple use services can be developed in an effective and sustainable manner (Smits et al., 2010). In the specific case of Colombia, with a particular context, in many ways different from other countries participating in the CPWF – MUS, it is required to identify, understand, evaluate and convert water needs of rural people in water demands for multiple needs, looking strategies for equity and poverty reduction. A substantial advance would be understanding demand for multiple purposes, since in Colombia, the extra quantities that is believed are required to supply water for both domestic and productive uses (Moriarty et al., 2004; van Koppen, et al., 2006), are perhaps one of the most conflicting issues between professionals from Agricultural and Health sector. This issue may be one of the "bottlenecks" for scaling up MUS in this country.

Hence, In Colombia, like in many other countries, water supply systems in rural areas are used by people to meet their multiple water needs. People use water from these systems for both domestic and productive activities, like micro – enterprises, keeping livestock, or crops. These activities support their livelihoods. Despite this reality, the legal and institutional frameworks that regulates water supply, provides water for drinking or irrigation purposes, separately. Small-scale productive uses of water – important for poor families' food security and income – are neglected for all sectors. As a result, rural water users engaged in small-scale activities do not fit into the legal and institutional structure, and their needs are often not meet, leading to poverty, food insecurity and people migration to the cities. Besides, as inhabitants of rural areas have different characteristics, including economic levels, those differences may be reflected on how different households within these systems benefit from the service levels provided.

Therefore, the intellectual problem I may help to solve through this research is:
The current design standard for rural water supply systems in Colombia allowing for 100 -150 lpcd for communities under 12,500 inhabitants is insufficient to satisfy sustainable and equitable water requirements for domestic use and production of different households within a rural water supply system.

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capacities, generate and document development outcomes, identify future research needs or areas for collaboration, and inform public and private sector policy decisions"

This research will determine through a case study, using the concept of water balance, the water requirements for domestic and productive uses, by different categories of households within a MUS system. These results will contribute to gain understanding on water demand and water availability in domestic rural water supply systems utilized for multiple uses, addressing issues of poverty, livelihoods, equity and sustainability, which could possibly be in the future an input or evidence to make policy changes needed in the water sector in Colombia.

1.3 Research aims and objectives

This research is intended to gain understanding on water demand and water availability in a domestic rural water supply system utilized for multiple uses addressing issues of poverty, livelihoods and equity.

This research has the following objectives:
Objective 1: To characterize groups of households within a MUS system according to aspects related to poverty, productive activities, livelihoods and access to water
Objective 2: To measure different components of the domestic water per capita consumption in households within a MUS system
Objective 3: To propose balances at the system and household level, including water demand for multiple uses and water availability, considering blue water and green water.

1.4 Research questions

This study is intended to answer primarily five questions:

- How different groups of households within a multiple uses of water service are characterized in relation to poverty, livelihoods and access to water?
- How these characteristics are related to water use and consumption?
- How much water is used in households in a multiple uses of water system exclusively for domestic purposes?
- How much water is used in a multiple uses of water system for productive activities?
- How blue water and green water are integrated to supply demands in a multiple uses system?

1.5 Research methodology

This research follows the case study methodology. This methodology has been extensively used in multiple uses of water research, especially within the CPWF-MUS (van Koppen & Smits, 2010). Four studies on MUS relevant to this research have been carried out, using the case study approach: Perez de Mendiguren Castresana (2003) in South Africa, Mikhail (2010) in Nepal; and in South American countries Smits et al. (2010) in Honduras and Roa & Brown (2009) in Colombia.

This method is selected because as stated by Yin (2003) is appropriate when "how" or "why" questions are being formulated, the investigator has little control over events, and the focus is on contemporary phenomenon within real life context. This method also contributes to the knowledge of individual, group, organizational, social, political and related phenomena, and allows combining a full variety of qualitative and quantitative evidence.

The research was divided in 3 phases: desk study, fieldwork; data analysis and report writing. During the desk study period, a systematic review on the relevant literature regarding MUS concepts and interlinked subjects was accomplished, together with the selection of the case study area and the review of the existing information relevant to the study regarding this place. In addition, a preliminary analysis of water consumption records of the households in the selected system was carried out. During this period, literature review and methodology draft chapters were the main outcomes and the establishment of contacts and logistic arrangements for the fieldwork.

The fieldwork period took place in Colombia from June 14th to July 16th 2010 and specifically from June 28th to July 9th 2010 in the selected system *"La Palma Tres Puertas".* The main methods used during this period were questionnaire survey, direct observations, water diaries, unstructured interviews, and flow measurements[3]. Information on people assets, productive activities, livelihoods, uses and access to water were elicited from the household survey; water consumption for domestic uses was established from a mix of strategies: interviews, observations, direct measurement, meters records and water diaries. Water consumption for productive uses was estimated applying the water balance approach, using the information provided from the household survey, household monitoring, meter records and climatic data. Water availability was estimated through direct measurements and the use of climatic information.

134 household surveys were applied in the study area, 6 households were monitored for domestic water consumption; 5 measurements were carried out on the water entering the system storage tank, and climatic information was compiled from the existing station in the area. One meeting was held with representatives of the system Water Committee and three meetings were carried out with the system caretaker.

[3] Further discussion on the data collection methods appear in chapter 4 of this document

After the fieldwork period, collected data was described, analyzed and discussed. Quantitative and qualitative data were analyzed and descriptive statistics were computed for several of the different aspects studied. These analyses were carried out with help of the Excel software. Results were presented in figures, tables and diagrams and discussed in light of what was learned from the literature review and looking to answer the research questions posed. Finally, conclusions were prepared keeping in mind the proposed objectives.

1.6 Scope

This research uses water balance concepts to understand water consumption and water availability in a multiple uses of water system. Within the scope of this research, water consumption is restricted to domestic use and productive uses in rural households of developing countries. Domestic uses include those traditionally studied by the domestic sector, and productive uses primarily comprise agriculture and animal husbandry, identified as the most important in rural Colombia. Water availability includes the green water (water in the soil available for plants) and blue water (fresh water), available to be used by households for domestic and productive activities. Both blue water and green water are general approached, given the scale of the available information. For example, the availability of groundwater is not considered in detail, since this is not the most exploited water resource by the hillside communities in Colombia, who generally rely on streams.

The unit of analysis on which this research concentrates is the household and the system. The household is understood as the home and its immediately surrounding land used by the family(s) living there. The system is understood as the set of households that are beneficiaries of the water provided by the water supply system. The system has administrative boundaries. The catchment area is not analyzed, although, it is a point of reference.

The water supply system is restricted here to collective systems delivering water through household connections. Non-centralized systems, or arrangements where people have to fetch water are not common in Colombia, especially in mountain areas. Water supply systems for irrigation are also out of this research, because as discussed in the introductory chapter, in Colombia there is a small area under irrigation and investments in such infrastructure are mainly made by the private sector. Water quality issues have been deliberately taken out as well, to reduce complexity to the analysis.

One of the limitations in this study is that a significant proportion of the reviewed information has been written manly by the promoters of the MUS concept framed in the CPWF – MUS project, since those are who have published almost what is available on the subject. However, this limitation was somewhat counterbalanced by the review of other documents about the aspects interconnected to the MUS concept, such as water consumption and water availability, written by other researchers and organizations or in other fields of application.

Besides omitting all the aspects above, no attempt was made to include issues related to technology for accessing water, management or financial aspects of water supply systems for MUS.

1.7 Intended readers

This document is intended for practitioners, researchers, implementers, policy makers, service providers, and community leaders of rural water supply systems, whether in the domestic or agricultural sector, especially in Colombia. To all those who want to move a little outside from the models or patterns of their professional training or field of performance and willing to increase their understanding, through this case, on the water demands of rural people, and how they are related to productive activities and livelihoods. This is a rather obvious relationship to the beneficiaries of the systems, yet quite unknown at other levels.

Also the same group of people, but not performing in the water sector; instead, fostering policies, programs or projects for poverty reduction, strengthening of production chains, promoting rural tourism, etc., All seeking to improve living conditions of people, but sometimes ignoring that water is required to undertake in a successful and sustainable manner, these strategies.

Finally, professionals from various disciplines interested in working together, especially those from the health and agricultural sector, trying to agree on service levels, to be sustainable, equitable, and appropriate to the needs of people, especially the poorest.

1.8 Structure of the report

The present document has been structured as follows:

Chapter 1 contains the introduction where the context is outlined, including relevant information about Colombia, and a background on the multiple uses of water topic leading to the problem definition and the questions to be solved. The methodological basis for the research and the methods used are listed briefly. Finally, the scope of work and a list of intended readers are presented.

Chapter 2 reviews the literature significant for the research; contains an overview to the linkages of poverty, productive activities, livelihoods and access to water, followed by the multiple uses of water concept and its current state, findings, challenges and research gaps. A section on planning of rural water supply systems under a MUS approach, and methods used to study some of the topics reviewed appear are the end of the chapter.

Chapter 3 is an overview to the study area, includes general aspects, water uses, water supply system, and review previous work on multiple uses of water previously developed in the area.

Chapter 4 describes the methodology addressed to research on the objectives. It includes besides the methods and instruments applied, the activities developed, aspects of data management, data analysis and limitations.

Chapter 5 presents and discuss the findings from the research activities carried in relation to the information on the literature review and the research questions formulated. It contains relations between categories of households based on water consumption and poverty, livelihoods and access to water; water consumption for domestic purposes in households within a multiple uses of water system; water consumption for productive activities; water availability and interaction between blue and green water to supply people´s demands.

Conclusions are presented in Chapter 6 regarding to the objectives drawn, the appropriateness of the methods used, and recommendations for further studies

At the end of the document, there is a list of references containing publications in English and in Spanish.

2 LITERATURE REVIEW

This chapter provides a review of the existing published literature on the MUS topic and on interlinked subjects central to it. It also describes the methodology used and the structure of the review. The chapter presents and discusses aspects such as poverty and access to water in rural areas; poverty reduction, Sustainable Livelihoods Approach, Demand Responsive Approach; MUS concept, water consumption for multiple purposes, water availability, water balances and budgets, and methodologies to research on the latter issues. At the end of the chapter, a section summarizing the core aspects of the literature review is drawn.

2.1 Methodology

The review started with the consultation of the available literature published by researchers and organizations that promote the MUS concept in order to acquire a general understanding of the subject. Researchers like van Koppen, Moriarty, Butterworth, Smits, Bolee and organizations such as IWMI, IRC and GWP were initially consulted. The literature available from these sources was in the form of books, conference papers, brochures and some few articles in academic journals. From this initial review, key concepts related to the topic and the particular purpose of this research were identified, broadening the review strategy to look for documents from other organizations and with a strongest focus on academic journals to identify the most recent findings related to the interest topic and concepts.

Information was obtained from the World Wide Web, and the Metalib database. Ideas object to review were water and poverty, Demand Responsive Approaches, Livelihoods Approach and Multiple Uses of Water. Terms and phrases searched were: water consumption, water demand, water availability, multiple uses of water, productive uses of water, water and poverty reduction, water and poverty alleviation, water sources, multiple sources, water supply systems for multiple uses, water availability, rural water supply, water use(s), domestic use/consumption, livestock use/consumption, agricultural use/consumption, water balances, on farm water balance, green water, blue water, water use in rural areas, household level, system level, farm level, micro-scale, meso-scale, domestic use, rural livelihoods, hydrological cycle, and water accounting, to name some. Boolean operators (AND, OR, NOT) were used to refine the search.

The review boundaries, broad category of concepts reviewed and how they relate according to the author, and as they are presented in this document are shown in Figure 2-1.

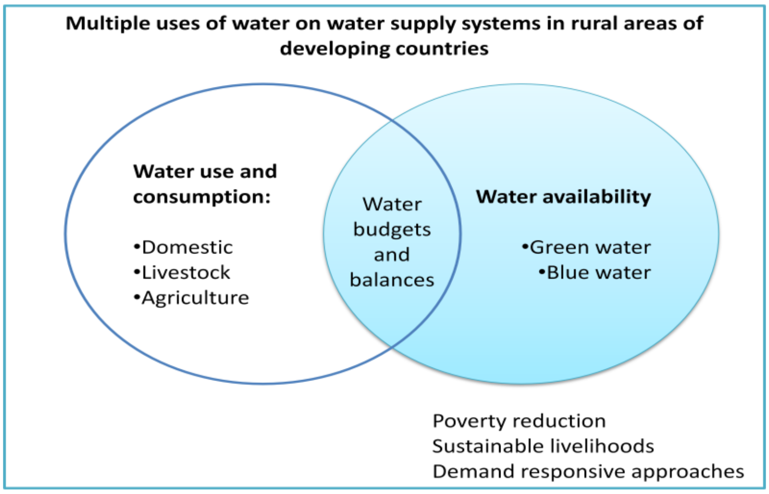


Figure 2-1 Relations between concepts approached on the Literature Review

Within the Metalib, databases such as Aquabase, Article First, Water Resources Abstracts, Illumina, Geobase, Science Direct, Greenfile EBSCO and Ingenta Connect were the preferred sources to carry out the search for the terms. The journals where the most relevant information was found were:

- Agricultural water management
- Agriculture and human values
- Irrigation and drainage
- Hydrology and earth systems science
- Journal of hydrology
- Consumer studies and human economics
- Land use policy
- Technovation
- Human ecology
- Physics and chemistry of the earth
- Water and environmental journal
- Water international
- Water resources development
- Water resources
- Waterlines

The Journal Physics and Chemistry of the Earth had the bulk of the most useful papers according to the purposes of this review. The information from journal articles was administered by using Refworks, where all the references were stored in folders according to the topics. A "snowball" method (UNC, n.d.) was followed in order to find relevant journal articles and the main authors on a specific topic. Available tools in some Databases like "Related articles", "Cited by", "Relevant terms from this article" and links to other articles referenced were helpful. Besides Metalib, Google scholar was also an important source of information.

Along with databases, information on websites from different groups and organizations such as musgroup, IWMI, FAO (Food and Agriculture Organization), HR Wallingford, WEDC and

GWP (Global Water Partnership) provide information to gain understanding on the concepts subject to review. Conference papers and journal articles were important to know about the methodologies, conclusions and state of the research in the topic.

2.2 Structure

This review has been divided into 6 sections. The first three sections are a sort of conceptual framework that has been divided on: poverty and access to water in rural areas; poverty reduction, Sustainable Livelihoods Approach, Demand Responsive Approach, and Multiple Uses of Water. The latter includes the main ideas of the concept, its conflicting issues and premises. Fourth section is about planning rural water supply systems under a MUS approach, and is intended to bring together different aspects of water demand and water availability, which are usually addressed separately by different sectors. Thus, a review on water use and consumption for domestic uses, livestock, agriculture, and the integration of the three is included. It also introduces a section on water availability, making a differentiation between blue and green water. Finally, water balances and water budgets concepts, models and frameworks are included. The fifth section reviews the methodologies that have been used to research on the MUS concept and its interlinked subjects: water use and consumption, water availability and water balances. At the end of the chapter, the core aspects of the literature review are summarized.

2.3 Poverty and access to water in rural areas

Poverty can be defined as a pronounced deprivation in people´s ability to obtain certain consumption goods or to function in society, and this is manifested through the limited circumstances of poor regarding aspects like income, education, health, security, self-confidence, power or rights. Poverty can be understood at different levels and correlated to different causes, among them: geographical isolation, low resource base and low rainfall. In rural areas, isolation leads to weak public services, communication and infrastructure, being the latter, one of the most important determinants of poverty at community level. At the household and individual level, poverty can be described through indicators such as household size, number of family members not in labour force to those in the labour force, gender of the household head, household employment, property and other assets. The human, physical, natural, financial, and social assets that poor people have allow them to escape from poverty. Some of those physical assets are land, cultivated areas, livestock, agricultural equipment, etc. Liquid assets and savings are financial assets. The availability and use of drinking water is often used as a social indicator of poverty (Haughton & Khandker, 2009).

International Agencies indicate that one billion people live on less than US$1 a day, and rural areas account for three quarters of these people and a for a similar proportion suffering from malnutrition. At least 1.1 billion do not have access to safe water, again with a more pronounced disparity between rural and urban areas in developing countries: while 92% of the urban population have access to water in urban centres, only 72% is covered in rural areas. It makes evident the correlations between access to adequate water and sanitation with differences on income and poverty (UNDP, 2003; UNDP, 2006; UNDP, 2007)

The statistics show that poor people are more vulnerable than the non-poor to lack of water supply and sanitation services, or to receive these services with lower quality or reliability (Yang et al., 2006; Hansen & Bhatia, 2004). In contrast, in high-income areas, people have significant higher levels of service provided at lower prices by public utilities, where 85% of the wealthiest 20% households have access to piped water through household connections compared to the 25% for the poorest 20% (UNDP, 2006).

Most poor people living in rural areas of developing countries, depend on agricultural production for their income and for them, lack of access to affordable infrastructure services, including intermittent or no water supply affect their possibilities to develop productive activities (World Bank, 2009). For these people, access to "improved" water sources which encompasses: quality, proximity and quantity are a key factor to support their livelihoods and to help them to escape from poverty, making possible to increase productivity, employment, reduce the risks associated with drought, diversify their income sources, and increase their security to undertake investments into higher value production chains. It explains the links between rural livelihoods, access to water and poverty reduction efforts (UNDP, 2006).

2.4 Poverty reduction, Sustainable Livelihoods Approach and Demand Responsive Approach

The call for actions which satisfy people needs and especially that target the poor have led to the formulation of concepts and tools to support interventions across the development sector. One of those "movements", the Sustainable Livelihoods Approach (SLA) was developed by DFID (Department for International Development) and suggests that interventions require a comprehensive analysis, people-centred (Moriarty & Butterworth, 2003) which includes an investigation of people´s assets, vulnerability context, institutions and policies, livelihood strategies and outcomes (Ashley & Carney, 1999).

SLA considers that people require a range of assets to achieve positive livelihood outcomes. Assets are divided into natural, social, human, physical and financial. Basic infrastructure, like water supply and sanitation (of adequate quantity and quality) is part of the physical assets, and lack of particular types of infrastructure is considered a core dimension of poverty (Moriarty & Butterworth, 2003). The framework introduces a "vulnerability context" related to the external environment in which people exist, including the trends and shocks that affect people´s livelihoods. It also involves "Transforming structures and process" understood as the institutions, organizations, policies and legislation that define livelihoods. Livelihood outcomes are the output of livelihood strategies, which are divided on more income, increased well being, reduced vulnerability, improved food security, and more sustainable use of the natural resource base (Ashley & Carney, 1999). All these elements are shown on the sketch in Figure 2-2.

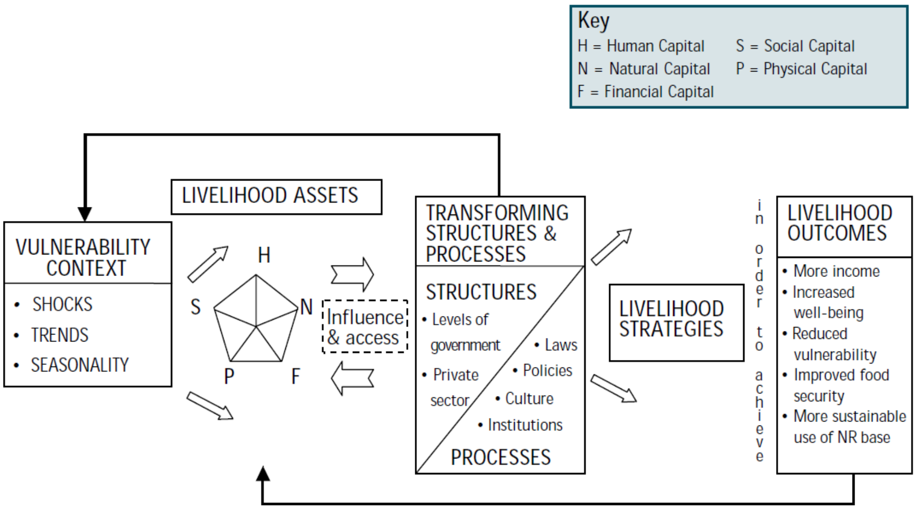


Figure 2-2 Sustainable Livelihoods Approach (Ashley & Carney, 1999)

From the water perspective, SLA focuses on providing access to appropriate infrastructure that enables people to achieve their livelihoods objectives (Ashley & Carney, 1999; Nicol, 2000) by recognizing that most people develop a range of activities to fulfil their needs and aspirations and that they have a variety of clear strategies to achieve them (Moriarty & Butterworth, 2003). As suggested by Nicol (2000) to apply the SLA to water supply interventions, it is required to analyse water resource use, through "unpacking" the components of demand at the household level.

The SLA is aligned with the Demand Responsive Approach (DRA). DRA states that provision of a particular service in order to be sustainable should be an "*informed expression of what people desire, together with the investments people are prepared to make, over the lifetime of the service to sustain it*" (Deverill et al. 2002). In water supply projects adopting a DRA imply that engineers and technicians need to assess demand according to people livelihood strategies, which in most cases, for rural areas, comprises needs such as garden irrigation, livestock watering, building blocks manufacturing, etc. Therefore, a more flexible approach is required allowing for interventions to consider those needs in conjunction with domestic needs, as long as people are willing to assume the costs of increased levels of service (Deverill et al. 2002; Moriarty & Butterworth, 2003). Figure 2-3 is a representation on the main determinants of water demand under the DRA.

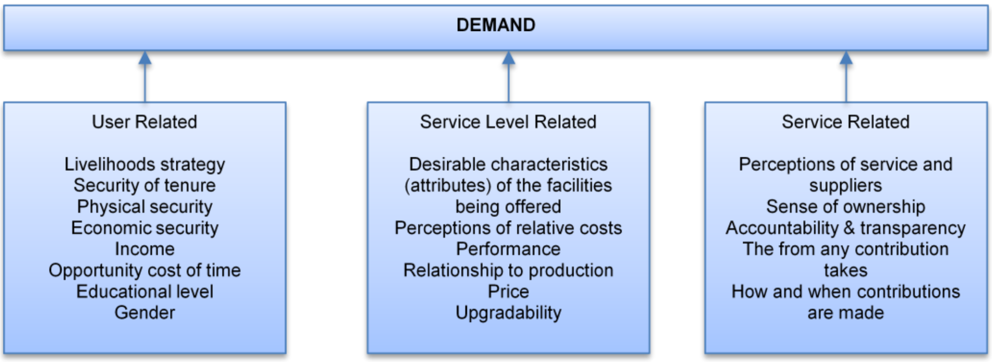


Figure 2-3 Main determinants of demand (Deverill et al., 2002)

2.5 Multiple Uses of Water (MUS)

Traditionally, the water and sanitation sector has been responsible to supply water for activities described as domestic, aiming to provide people with clean, reliable and safe water to achieve health improvement, and the sector have performed with the mandate of providing "*all with some high quality of water*" (Moriarty & Butterworth, 2003; van Koppen, et al., 2006). On the other hand, the agricultural sector has been in charge of water provision for food production. This approach has meant that activities such as backyard gardening, fishing and livestock keeping have been ignored by both sectors and in the end, in many cases, nobody is accountable for them (IWMI et al., 2006).

Contrary to this sub-sectoral approach, in rural households water supply systems are used for both, domestic and productive activities. Examples of productive activities are crop irrigation, horticulture, gardening, livestock, fisheries, food processing, brick making, weaving, pottery, handicrafts, and other small business; fuel wood and fodder production, etc. In those activities, water provision is an important enabling resource, significant to achieve well-being and reduce poverty (Van Koppen et al., 2009; Moriarty et al., 2004).

Referring to the possibility to use water for income generation activities, van Koppen, et al. (2006) highlighted "it *brings multiple benefits that mutually reinforced each other for the better*": food production is essential for nutrition and health; health depends on access to and correct use of water and sanitation services; good health increases productivity, leading to more food and income, which allow paying for health services and adopting health prevention measurements; better nutrition decreases susceptibility to disease, reduce drudgery, frees up time for productive activities, domestic child care or schooling.

Despite the potential benefits of multiple uses of water, especially for poor people, these small-scale uses are normally ignored in formal planning process done by the different subsectors involved. In the domestic sector, the accepted definition of basic needs leads to design norms that frequently are insufficient to provide the quantities of water required to develop home-based activities, limiting the livelihood possibilities of poor people (Moriarty & Butterworth, 2003). In general, international, national norms and guidelines used for planning, account for basic needs or basic human rights having into account quantities required only for drinking, cooking and personal hygiene, in a range of 25-40 lpcd (van Koppen, et al., 2006). In opposition to this “paradigm” conclusions from the international symposium on “Productive uses of water at the household level” in South Africa in 2003, indicated that quantities of water in the range of 50 - 200 lpcd were adequate for meeting multiple basic human needs (Butterworth et al. 2003). The latter range is similar to the quantities supplied exclusively for domestic uses to urban people in developed countries (van Koppen, et al., 2006).

Due to planning practices such as designing for a lifespan, allowance for losses and other engineering considerations, sometimes unplanned uses can be absorbed by the system (van Koppen et al., 2009), at least during the first years of infrastructure operation. Although, when the extra amount of water required to support people livelihoods is not provided, a variety of problems can threaten the sustainable provision of the services, resulting in interventions that are not sustainable or insufficient for real people needs. Generally, these failures have more impact on the poorest, which are less capable to cope with them (Moriarty & Butterworth, 2003). Some of the reported failures are damage to infrastructure, disruption of allocation schedules, deprivation of tail-enders and increase of conflict (van Koppen et al., 2006; Moriarty et al. 2004). A widespread solution adopted to minimize these problems is the formulation of national and local regulations to ban productive uses in domestic schemes, although, these solutions usually fail and just contribute to exacerbate conflicts (van Koppen et al., 2006).

The MUS concept has emerged in response to these challenges. van Koppen et al. (2006) define it as an approach that *“looks to acknowledge people multiple water needs and their full participation from the outset on water projects to really meet people water demands as an strategy to enhance people livelihoods, contribute to poverty alleviation and achieve sustainability of water systems, without deprivation of the supporting water resources and the environment”.*

In relation to the environmental sustainability, the approach recognizes that for meeting their water demand, in most cases, people use multiple sources at homestead scale to augment the available water supply, allowing households to employ water of different qualities for different purposes (Scheelbeek, 2005). The extent to which multiple sources are used varies from case to case. Experiences in Thailand showed that people combine up to nine water sources to supply different needs as result of a National Policy that promotes intensive production and recycling of water and nutrients at the homestead level (van Koppen & Smits, 2010). In contrast, some regions in Colombia are at the other extreme, where piped systems are the main source of water for all uses (van Koppen et al., 2009).

The promotion of various water sources is considered within this concept as a promissory alternative to enhance the total quantities required, stimulate water reuse and increase the resilience to water availability (van Koppen et al., 2009).

The range of potential uses and sources that can be included under MUS requires for implementers to offer a variety of options to each community for their selection that has to be the result of an understanding of the local context in relation to water uses, water resources and available technology. To do this, a call is made to take into account that different communities have different priorities, preferences and availability of water resources and this situation is extended to the different households and population groups within communities (Mikhail, M., 2010).

2.5.1 Conflicting ideas of MUS

Water quantity: To allow small-scale productive activities at the household level, it is required to supply bigger quantities of water compared to those required just for domestic needs. This is a major issue, especially in water supply systems for domestic uses, where productive uses occur (van Koppen, et al., 2006). At all levels, from policy makers to users, voices have been heard arguing that this major quantities could threaten sustainability and that is better to supply small quantities of good water quality. MUS advocates for provision of a household supply for both basic needs and productive uses where water needs are anticipated and planned during the designing stage. It involves as a precondition assuring that enough water is available according to people requirements, but at the same time, that allocations are sustainable to avoid infrastructure or environmental damage, conflicts with prevailing users, and ensuring financial sustainability of service provision (Moriarty et al., 2004). To achieve this, some proposed alternatives are increasing capacity of abstraction, storage and delivery infrastructure, and considering multiple sources for multiple uses (van Koppen, et al., 2006).

Water quality: In systems supplying treated water, it is considered a waste to use this water for productive activities like irrigation or cleaning piggeries (Moriarty and Butterworth 2003; van Koppen, et al., 2006; Moriarty et al., 2004). In systems that supply untreated water, there are issues related to health, when this water is used for drinking purposes (van Koppen, et al., 2006). MUS promoters argue that, providing better access to larger quantities of water, together with household treatment technologies and hygiene promotion, may improve health more effectively than often ineffective measures to ensure that high water quality is supplied (IWMI et al., 2006). This is an important argument in the case of rural areas in developing countries where, regardless of presence or absence of centralized water treatment, in practice, for several reasons, households do not receive drinking water quality. Reasons to support this argument include that systems and treatment infrastructure are not properly operated, technology have not being adequately transferred, lack of inputs, lack of skilled personal, pollution of the treated water during transmission, distribution or household storage, etc. (Moriarty et al., 2004). Besides, in many situations the sources exploited, groundwater or streams, can deliver water quality acceptable for domestic uses, sometimes even for drinking (van Koppen, et al., 2006).

There is still debate to come up with appropriate alternatives to harmonize the different people´s water needs in terms of quantity and quality for the different uses in a sustainable, efficient, safe and cost – effective way. A combination of treatment at the point of use and hygiene promotion looks a promising alternative to achieve these purposes (Nath et al., 2006).

Equity: the orientation of the water sector that has been discussed, to provide some water of good quality for all, giving priority to increase coverage, is a concern since it is believed that MUS services require more water resources and are more expensive (van Koppen, et al., 2006). Currently, part of the research agenda on MUS is oriented to develop cost-benefit studies in order to probe the validity of this hypothesis. There is also concern with regard to the way benefits of MUS services are distributed across different population sectors, since there is a risk that the interventions on MUS allow rich people to exploit the opportunities of the highest levels of service to the detriment of the poorest (Mikhail, 2010). For instance, in rural Honduras Smits (2010) found within water supply systems for multiple purposes that water consumption varies according to user categories, defined based on household head occupation. In this study, people in the labourer category have negligible water consumption for productive uses (2.7 lpcd) compared to those on the large-farmer category, with consumptions around 480 lpcd. Another study by Hadjer (2005) addressing levels of consumption according to social status, found that the rich consumed up to 50% more water compare to poor households. MUS promoters suggest setting operational rules and financial incentives to avoid inequality (van Koppen, et al., 2006). Equity aspects require to be further studied and there are still many questions to formulate and solve.

2.5.2 Premises

Some of the main arguments to defend the MUS concept, stated by the main researchers (van Koppen, Moriarty, Bolee, Smits, Butterworth and their organizations (i.e. IWMI and IRC) are listed below

- *Water quantities required for small scale productive activities, which support people livelihoods are minor, if not negligible, being the issue to provide the poor with financial, technical and institutional resources that allow them to have access to the required infrastructure to satisfy their water needs*
- *Planning and design of services need to be responsive to, and based upon, a thorough understanding of people's livelihoods taking as the starting point for planning, people multiple water needs at preferred sites*
- *Planning and design of services using naturally available water resources need to be efficient, equitable and sustainable. Water from multiple and conjunctive sources should be used and reused to meet multiple needs. The knowledge of communities and service providers should be increased to monitor water resources and the relevant interconnections between different parts of the hydrological system, sites and periods of competition for the available sources. Conflict resolution abilities are required to negotiate the protection of basic human, domestic and productive needs and the already prevailing users.*
- *A multiple use approach involves: (1) assessing the range of water needs in collaboration with end users, ensuring that women's and men's multiple water needs are equally articulated, translated into "water demand characteristics" such as: quantity, quality, site, timing/period, and incorporated into the design; (2) examining the water sources available— from rainwater to wastewater; and (3) matching water supplies to needs based on the quantity, quality and reliability required for various purposes*

2.6 Planning rural water supply systems under a MUS approach

As previously mentioned the MUS concept looks for the consideration of the small-scale productive uses of water in conjunction with domestic uses from the planning stage of rural water supply systems and its extension to the project cycle life, aiming for poverty reduction, support of people livelihoods and sustainability. For planning systems under these purposes, demand for water should be based on the range of people uses and an integral consideration of the potential sources available, since the required water quantities may be higher than those traditionally supplied by the domestic water sector. Therefore, the way to come up to water use, consumption, and water availability on the water sub-sectors (i.e. domestic and agriculture) should be revaluated. An attempt to integrate the concepts necessary for this is developed in the subsequent sections:

2.6.1 Water uses and consumption

In rural communities homesteads generally comprises the house where people have shelter and relatively extensive areas to develop agriculture activities that provide their livelihoods. In these homesteads, besides domestic uses, water uses are related to irrigation for growing vegetables, staple food, wood for fuel, fruit and trees; livestock watering, coffee processing, and small business such as beer brewing, ice-making, catering, pottery, hair salons, laundry, car washing, etc. In these contexts, production is diversified, and each water use is an important factor to produce livelihood outcomes such as household income and food security (Van Koppen et al., 2009). Some of the most representative categories of water uses at rural homesteads are described below:

Water for domestic uses: Norms by international organizations suggest a minimum requirement of 20 l/day from a water source within 1 Km of the household, as a quantity sufficient for drinking, basic personal hygiene and for physical well-being and dignity. This quantity increases to 50 lpcd when bathing and laundry needs are included (UNDP, 2006).

In different countries there are different basic needs figures used for planning purposes, for instance for South Africa those are 25 lpcd, 55 lpcd in India (Moriarty et al., 2004), 60 lpcd in Zimbabwe and 40 lpcd in Swaziland (HR Wallingford, 2003). Sometimes those targets are smaller for rural areas in comparison to targets for urban areas as in the case of Colombia, where the target for areas less than 2500 inhabitants is from 100 - 150 lpcd and for communities with population higher than 125000 there are not superior limit for water provision specified on the designing guidelines RAS – 2000 (Mindesarrollo, 2000).

Figure 2-4 presents the average water use per person per day for developing and developed countries prepared by Shen (2010) with data from the United Nations Human Development Report 2006. This Graph shows the differences on water use between developed and developing countries going from negligible quantities in Mozambique to levels inferior to those promoted by International Agencies as minimum requirements (50 lpcd) for countries such as Rwanda, Uganda, Ethiopia; to the other extreme of United States and Australia, where the per capita consumption exceed 450 lpcd. In the case of developed countries, the average water use of European people is more than 200 lpcd (UNDP, 2006), and UK appears as the developed country with the lowest per capita consumption in the Graph, with about 150 l.

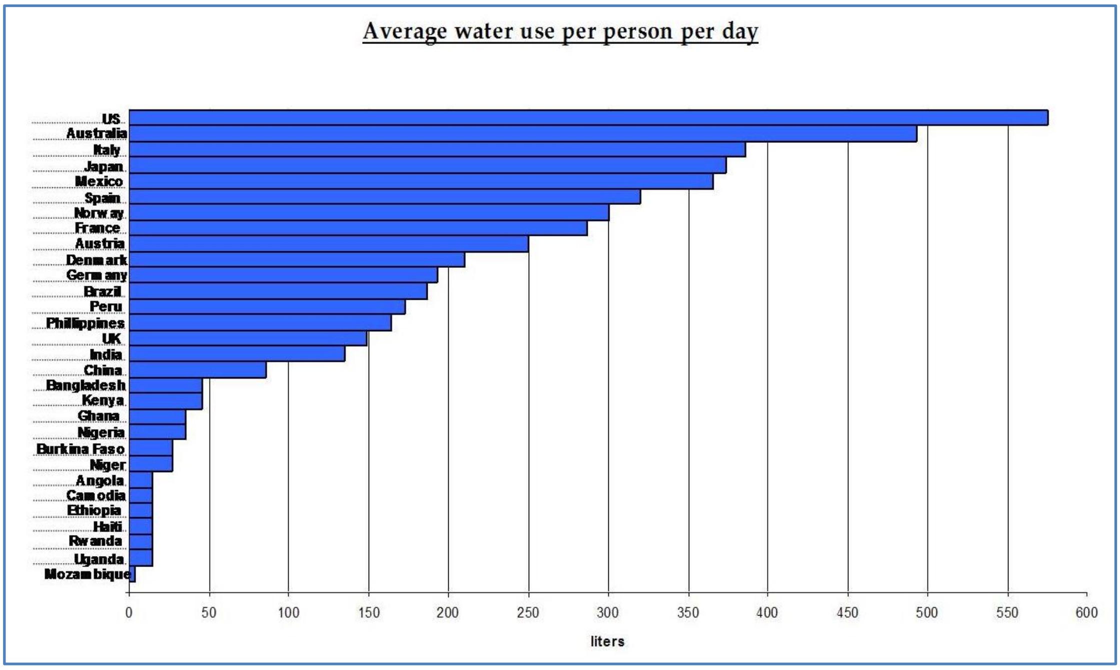


Figure 2-4 Average water use per person per day (Shen, 2010 based on UNDP, 2006)

Table 2-1 shows some figures of water consumption for the most common domestic water uses according to different authors. Reported figures, except Gleick (1996), are related to service provision when the supply is from individual household connections. Roman (2002) provided German data considered similar to most of the average consumption in Central European Countries and Nozaic (2002) reported data used for planning purposes in India. Data from Roa (2005) and Barrios (2008) were directly measured in rural households in Colombia on exploratory studies.

One of the limitations that can be seen from this information is that categories used for the authors to report these figures differ, except for uses such as sanitation, bathing and laundry (washing clothes). Categories that are frequently reported in different ways or reported together are drinking water, cooking, dishwashing and housekeeping. Some authors have even grouped all the hygiene-related activities including personal and household hygiene in one category (Howard & Bartram, 2003). This grouping is inconvenient under the new trends that promote the use of water of different quality according to the requirement of each category of use (van Koppen et al., 2009; Ratnaweera et al., 2006). Except for Gleick (1996), which figures represent a standard minimum requirement, it can be seen that total water needs for domestic uses in pipe systems are in the range to 75 – 178 lpcd, being the data reported by Barrios (2008) the maximum within all categories of uses. In this case, the author suggests the availability of multiple sources and abundant water resources for the homesteads where the study was carried out. The opposite situation was reported by Roa (2005) which researched in an area previously affected for a water shortage, which leads people to adjust their consumption practices. Drinking and food preparation is the category with the narrow range of consumption for all authors, as can be expected, since this is the priority use, which consumption is less affected by aspects such as water availability, access or price.

Table 2-1 Water quantities for most common domestic uses according to different authors

Domestic water uses	Gleick (1996)	Roman (2002)[a]	Nozaic (2002)[b]	Roa (2005)[c]	Barrios (2008)[d]	Range
Drinking water (lpcd)	5		5			5
Sanitation(lpcd)	20	35	18	13	41	13 – 41
Bathing (lpcd)	15	46	20	12	21	12 – 46
Cooking and kitchen (lpcd)	10					10
Drinking and food preparation (lpcd)		5		4	4	4 – 5
Dish washing (lpcd)		8	15	11	28	8 – 28
Laundry (lpcd)		16	20	27	79	16 – 79
Cooking (lpcd)			3			3
Other (lpcd)		8				8
Housekeeping (lpcd)				5		5
Brush teeth and hand washing (lpcd)				3	5	3 – 5
Total (lpcd)	50	118	81	75	178	50 – 178

a German data, considered similar for water consumption to those in Central European countries, Roman quoted Globus, statistische Angaben: Bundesverband der Deutschen Gas und Wasserwirtschaft. b Indian data Nozaic quoted the Design Manual for water supply and treatment (1991). c Households within a catchment in a rural area of Valle del Cauca Department in Colombia. Values are the rounded average of reported Max and Min values for each consumption category. d Three households in Quindío Department in Colombia. Values are the rounded average of the three reported data

Water for livestock: Livestock production systems support about 4 billion people, constituting the livelihoods of at least 70% of the world´s rural poor. About 20 million km^2 in Central and South America are dedicated to this purpose and from those, 70% accounts for non-irrigated or rangeland systems. Livestock are an important source for family income providing products as milk or meat, manure, farm power, etc. and are a vital strategy to enhance income and cope with unexpected family expenses or shocks (Peden et al., 2007).

For livestock production systems, even at small scale, the benefits derived depend on adequate water provision. In reference to the concerns expressed by different authors in relation to the impact of livestock production systems over water resources at global and local scales, specially the large volumes "thought" necessary to produce human food for livestock, Peden et al. (2007) bring out, how for more poor regions in developing countries, livestock keepers feed their animals mostly with crop residues, suggesting that water requirements are not as great as is thought.

There is not much literature related to water consumption by animals and even the most recent sources refer to a report by Pallas (1986) "Water for animals". According to this report, livestock water consumption is influenced by food intake, quality of the food, air and water temperature. In relation to the demand for food, it varies according to the type and class of animal and life stages such as pregnancy, lactation or fattened. Other aspect is the content of water in the forage, which depends on the season, i.e. during the wet season grass may contain as much as 80 percent water. Content of salts on the forage is another factor i.e. major content of salt in plants used as forage in semi arid areas increase water demand. The water requirement also increases with air temperature.

Pallas (1986) also defines “voluntary water intake” by livestock as the quantity of water which cannot be provided by the moisture content of the forage. This is the amount of water to consider, when water supply systems will allow for livestock demands. Table 2-2 presents some data regarding water demand for livestock reported by different literature sources.

Table 2-2 Typical water consumption figures for livestock

Type of livestock	Water consumption (litres per head per day)						
	Nozaic [a] (2002)	HR Wallingford (2003)	Ospina (2009)	Roa[b] (2005)	Peden (2007)	Barrios[d] (2008)	Range
Beef cattle	25 - 45	25 - 45	25	8 - 14	40 – 45 [c]	9	8 - 45
Dairy cattle		40 - 60			70 – 85 [c]	54	40 - 85
Horses	20 - 35	30 - 45	20			10	10 - 45
Pigs	10 - 15	10 - 20	15	7 - 10		14	10 - 20
Chicken, litres per 100 birds per day	15 - 25	30 - 40	20	15 - 37			15 - 40

[a] Data reported for Indian cattle. [b] Households within a catchment in a rural area of Valle del Cauca Department in Colombia. Values were rounded [c] Data reported for Canadian cows. [d] Three households in Quindío Department in Colombia. Values are the rounded average of the three reported data

Table above shows those differences stated by Pallas (1986), regarding the disparity in water consumption according to the purpose of the animal, in the case of cattle (dairy or beef). This difference can be considered in order to decide livelihoods strategies in water stress areas. Data from Roa (2005) and Barrios (2008) are minor since those correspond to the defined voluntary intake.

Water for agriculture: Worldwide, agriculture is the largest user of water, accounting with 70% of the total consumption (UNEP, 2007). This water share is very much higher in some developing countries like Pakistan (97%), India (93%), China (87%), and Egypt (86%). In Colombia, this proportion is 61% (IDEAM, 2008).

Agriculture uses water through evapotranspiration, transpiration by plants and evaporation from soils. In recent years there has increased the interest to make a distinction between the water withdrawal for agricultural purposes from rivers, reservoirs, lakes and aquifers, from the rainwater stored in the soil and directly used by the plants. The first one has been called “blue water” and the latter “green water” (Molden et al., 2007). Agriculture which uses only green water is called rainfed. Irrigation is required when the water requirements of the plants cannot be satisfied only with the rain and thus, blue water need to be added to maintain adequate soil moisture levels for crops to achieve their potential yields. Globally, around 80% of agriculture evapotranspiration is directly from green water (Molden et al., 2007; Rockstrom et al. 2007). In Latin America, the percentage of cultivated land under rainfed systems is almost 90%, supporting both permanent crops such as rubber, coffee, and annual crops such as wheat, maize and rice (Molden et al., 2007). It makes important to understand this branch of the hydrological cycle for livelihoods and food production.

Irrigation water accounts for the majority of crop water use in areas subject to dry season or in arid areas. However, many production systems classified as rainfed involve applications of supplemental water to alleviate plant stress in special stages of their production cycle and to reduce vulnerability of farmers during short term dry spells (two or three weeks) or seasonal drought (Sulser et al., 2009).

Estimation of water demands for agriculture, depending on the purpose of the assessment, may require extensive data such as cropped area, crop growth periods, crop evapotranspiration coefficients by crop growth stages, reference evapotranspiration, cropping patterns, water use efficiency, effective rainfall, soil and water quality (salinity), water infrastructure type, water management, etc. (Rosengrat et al., 2002). FAO have developed procedures, guidance and tools that allow making crop water requirement estimations by using the mentioned information. Procedures for detailed estimations are extensively described in Allen et al. (1998) and Brouwer et al. (1992).

Water for other agricultural uses - coffee processing: The quantity of water required for coffee processing depends mainly on three factors: cropped area, productivity and processing system (Ospina, 2009).

Coffee can be processed in two ways - dry processing and wet processing. Wet processing is regarded as producing a higher quality product and therefore, is the most widespread method in productive regions in the world (Practical Action, n.d). In Colombia, the wet process is developed under three main systems described by Ospina (2009):

- Traditional system, where all cleaning processes involve water use; its water requirements are 40 l/kgPC (litres per kilogram parchment coffee)

- System bath-tank, which combines dry and wet processes and the use of by-products. It is suited for small and medium growers and the water requirements are 4.2 l/kgPC
- Belcosub system, developed to promote sustainability in the use of water and wastewater management on the coffee processing practice. It requires 1 l/kgPC. The main difficulty for its implementation is its high costs, therefore it is mainly used by large producers

As can be seen from these factors, water requirement for processing directly depends on coffee production. Several characteristics affect productivity in coffee plantations, i.e. soil, climate, density, age, type of coffee, light, altitude, latitude. Smallholders in productive regions more commonly practice the “shaded coffee” system, which uses trees to provide different levels of dark. This is mainly used in areas with limitations for proper development of the crop, soil or climate conditions. In Colombia reported productivity in these systems is around 500 - 1000 kg PC/He (Parchment Coffee per Hectare) (Cenicafé, 2006)

Water for multiple uses: A household water supply in the range of 50 – 200 lpcd was identified for those present at the Johannesburg Symposium on 'Water, Poverty and Productive Uses of Water at the Household Level' in 2003, as an adequate quantity for multiple needs and the sustainable use of the water sources. Compare to survival norms of some countries, this quantity is large, although is similar to quantities provided in urban supplies (Moriarty et al., 2004).

In rural areas, as has been discussed, as most of the income-generating activities depend on water, these uses may account for significant proportions of the water demand. Within this type of communities, demand estimation may require greater depth of analysis of household livelihoods, potential uses, required quantities and their daily, weekly, monthly and seasonal variations for a more informed decision about the required service level (Nicol, 2000). The analysis should be extent to effective alternatives to meet those demands (Moriarty et al., 2006) that maybe requires for the Engineers to investigate options with which they are not familiar (Deverill et al., 2002).

Findings regarding level of service for MUS are summarized on the MUS ladder proposed by van Koppen et al. (2009), which appears in Figure 2-5. The figure indicates that when water is available on or around the households from one or more sources, most users, use water for productive activities, even when the quantity provided is below 20 lpcd. When service level is in the range of 50-100 lpcd, productive uses are more substantial and from 100 – 200 lpcd all domestic needs and several different productive activities can be developed. The ladder representation aims to establish a comparison with the ladder proposed in the water sector

(Howard and Bartram, 2003), which suggests that at each service level from 20 to 100 lpcd, all uses are exclusively domestic.

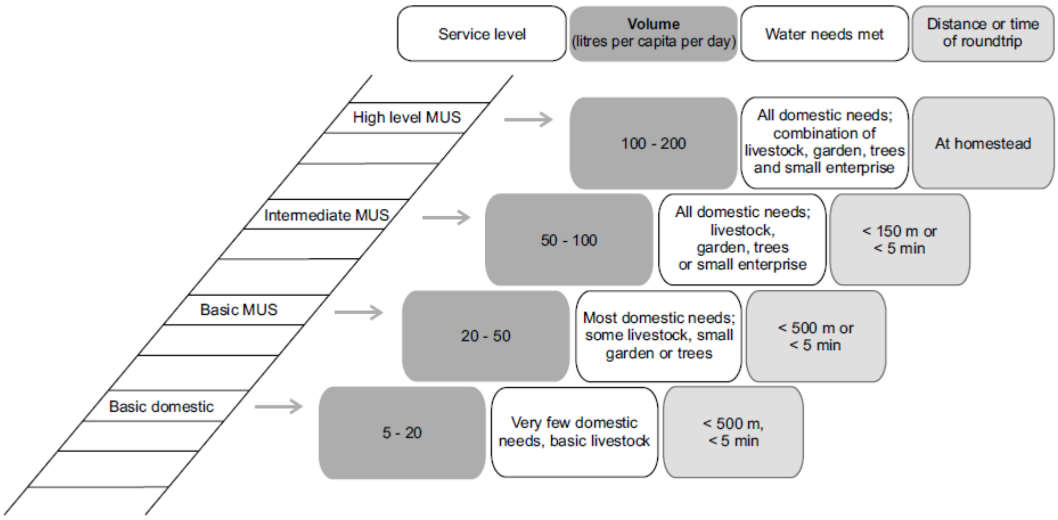


Figure 2-5 Multiple-use water ladder (van Koppen et al. 2009; van Koppen et al., 2010).

Table 2-3 summarizes quantities of water used for people in MUS systems, either designed for MUS or planned for single uses, but used for multiple purposes (Van Koppen et al., 2006). All the cases correspond to household connections. It can be seen from these figures how domestic uses are less variable, and productive uses appear in a more wide range. In the case of South Africa, the proportion of water used for domestic activities is related to the Basic Needs policy existent in this country. Domestic values from South American Countries, Colombia and Honduras, are similar; and it is interesting that the 45 lpcd used for planning purposes in Nepal includes livestock use as part of this allowance.

Table 2-3 Water consumption for MUS systems according to different authors

Source	Perez de Mendiguren Castresana (2003)	Roa & Brown (2009)	Smits et al. (2010)	Mikhail (2010)
Country	South Africa	Colombia	Honduras	Nepal
Domestic	25 lpcd	67 lpcd	64 lpcd	45 lpcd[a]
Domestic + productive	65 lpcd	250 lpcd	123 lpcd	400 – 800 l/day/hh[b]

[a] This figure include an allowance for livestock considered as part of domestic use. [b] hh: Household

Relating to productive uses, the reported values are more variable. In Nepal, this range can be associated to household´s economic capacity. Mikhail (2010) mentioned, well off people have been able to have more access to some irrigation technologies that has been promoted, while the poor have had less access and this range may be linked to that situation. Something similar has been reported by Smits et al. (2010), where the value of 123 lpcd is the average consumption of different population groups (farmers, labourers, ranchers, etc.) where some categories use far more water in productive activities than other. In their paper, Roa & Brown (2009) also make differences on the water quantities required in this area when people have different productive activities, which can be linked to assets as well. Therefore, the productive use of water may depend on several factors, not only level of service and quantity provided.

2.6.2 Water availability

Globally, from the total precipitation over the continents only a third becomes runoff in rivers and recharge aquifers (blue water) and the remaining two thirds infiltrate into the soil (green water) to supply the plant cover and returns to the atmosphere as vapour flow (Falkenmark & Molden, 2008). Thus, blue water is the measured and managed freshwater resource, in its liquid form available to be withdrawn for different uses to satisfy the demands from the domestic, industrial, hydropower, livestock and irrigated-agriculture users, and also to sustain ecosystems in rivers and lakes (UN 2006b; Molden 2007; Rockström et al., 2003; Hoff et al., 2009).

The understanding of the hydrologic cycle, with its different components and the balance of available water flows and the needs of agricultural, industrial and domestic sectors, contributes to the sustainability of the quantity and quality of water resources (DFID, 2001). However, people traditionally have had more interaction with the blue water, due to abstractions for different purposes through a wide variety of infrastructure, and in a less evident way, by modifying vegetation and causing alteration of soils and water flows (Falkenmark, 2003).

Because human interactions have been more related to blue water, it has been more widely studied. However, in recent years due to the increased pressure on this resource, much attention has turned to the green water, especially taking into account the need to feed a rapidly growing world population, being agriculture the largest user of water at global scale (Rockström et al., 2003).

In the particular case of agriculture, irrigated areas uses blue and green water, while rainfed areas receives only green water (Hoff et al., 2009). According to Rockstrom et al. (2003) within the on-farm water balance, soil evaporation is generally 30-50% of rainfall and it can be even greater in cultivated areas of semiarid regions, while surface runoff is reported as 10-25%. These figures make evapotranspiration, the productive green water flow, just 15 to 30%. The motivation for increasing that proportion of productive green water flow for food production has generated a new “paradigm”, oriented to the management of precipitation as a key resource that enables food production allowing for less blue water abstractions (Falkenmark et al., 2004). For this, some of the proposed alternatives are rainwater harvesting and supplementary irrigation. Clearly, those can be adopted in places where there is sufficient average rainfall during the crop season, so that farmers can collect and store surplus water and use it in critical periods (Molden & Fraiture, 2004; Hoff et al., 2009; Rockström et al., 2003).

In order to evaluate water resource or to balance its availability against different demands, information regarding the components of the hydrological cycle and its associated human and natural ecosystems is required. GWP (2000) highlights the importance to acquire knowledge about the water resources that integrate the occurrence on space and time of blue water, its quantities and qualities together with green water flows to estimate the water necessities for any proposed development. In order to do this, water balances and budgets are important tools to be explored.

2.6.3 Water balances and water budgets

Water budgets are tools for effective managing and planning of water resources (Healy et al., 2007). These budgets quantify the components of the hydrological cycle based on water balance concepts. Water balances consider water inflows and outflows at different levels from global scale to small units such as a plant. The first step to perform a water balance is to define a domain and its spatial and temporal boundaries, since the conservation of mass principle requires that over the period of interest, inflows are equal to outflows plus any change of storage within the domain (Molden, 1997). This is represented by Equation 2-1.

$$\textit{Flow In} - \textit{Flow Out} = \textit{Change In Storage}$$

Equation 2-1

Equation 2-1 can be adapted according to the goals and scale of a particular study. Most hydrologic computer-simulation models are based on the water balance equation and thus, are water-budget models. Simple models may provide a rough overview of a domain, but insight on the process that describe water movement within the domain can be achieved using more complex models that are generally more expensive (Healy et al., 2007).

Water budgets have been more widely used in the irrigation sector. Molden (1997) suggests that water budgets can be applied at field, service and basin level with different aims, depending on the scale. At the field level, looking to increase productivity per unit of land and conserving water; at the service level focusing on the analysis of irrigation services; and at the basin level, aiming to investigate agricultural and non-agricultural water uses. In a broad sense, basin level models can include the water supply system, the delivery system, the water users system (agricultural, municipal, industrial), drainage collection system and basin hydrological characteristics. Additionally, besides the natural and physical processes, the physical projects (hardware) and management policies (software) should be taken into account on the modelling (McKinney et al. 1999). Figure 2-6 shows the schematic representation of a river basin modelling based on water balances, including only the natural and physical process.

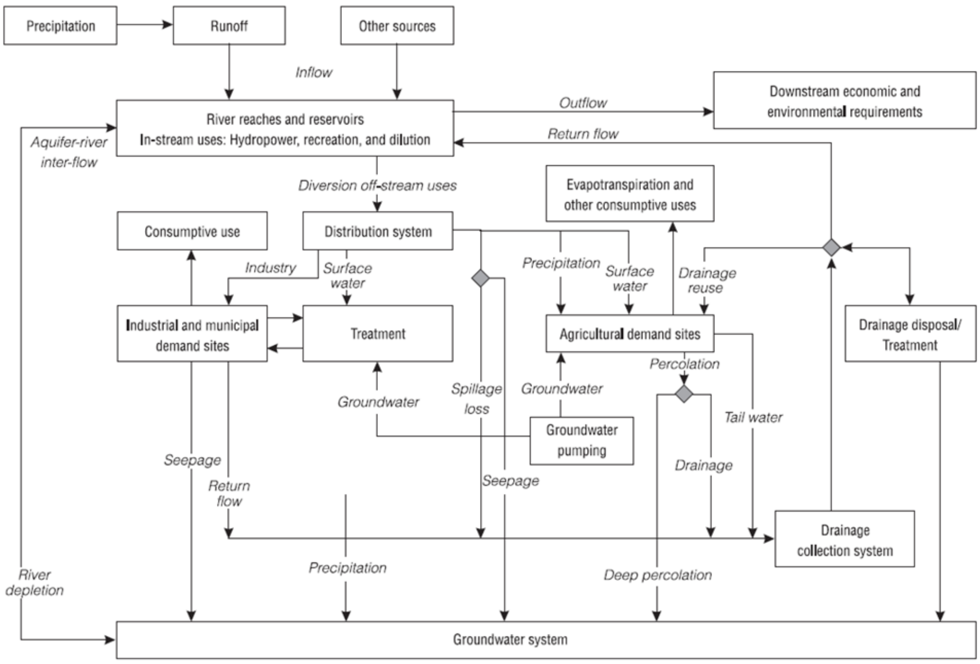


Figure 2-6 Schematic representation of river basin processes (McKinney et al, 1999)

Since water is managed in more areas according to governmental boundaries, water budgets can also be applied having political units as domains, for addressing issues as the available quantity of water, water demands, and the rates to which supplies are replenished. In these cases, there are significant uncertainties regarding measurement of surface and groundwater flows across the boundaries of the analysis unit (Healy et al., 2007).

Some models based on water balance and water budget principles at different scales are described below:

Impact water model (Rosengrat et al., 2002): This model is used to investigate the impact of water availability on food supply, demand and prices at various scales over a 30-year horizon from river basins to global level. It includes water demands as irrigation, and non-irrigation (domestic, industrial and livestock). Irrigation demand is projected based on irrigated area, crop, soil, climatic parameters and water use efficiency. Livestock water demand is assessed based on livestock production, water price, water consumptive use per unit of livestock production, including different species. Industrial water demand depends on income (GDP per capita), water use technology improvements and water prices. Domestic water demand is estimated based on projections of population, income growth and water prices. Water flow for environmental, ecological, political purposes and other uses such as recreation, hydropower generation and navigation are also considered.

In terms of the hydrological cycle components, the model takes into account: precipitation, runoff, evapotranspiration, and inflow from transboundary basins; for storage, it considers reservoir and soil storage. The model makes estimations on renewable water, total water availability, maximum allowable water withdrawal, effective water supply for irrigation and irrigation water supply reliability. Generated projections are based on changes in water supply infrastructure and water allocation and management policy.

IWMI Water Balance Framework (Perry, 1996): This framework has been developed for the irrigation sector. It can be applied at field level or service level. Inflows of water are canal delivered supplies and rainfall, and the outflows are crop evapotranspiration, non-beneficial evaporation/ evapotranspiration, drainage runoff and net flows to groundwater. The model links those elements through seepage from channels and irrigated fields, runoff, infiltration, evaporation and transfers through pumping from groundwater and pumping from drains. Figure 2-7 shows a schematic flow diagram from an application of the model.

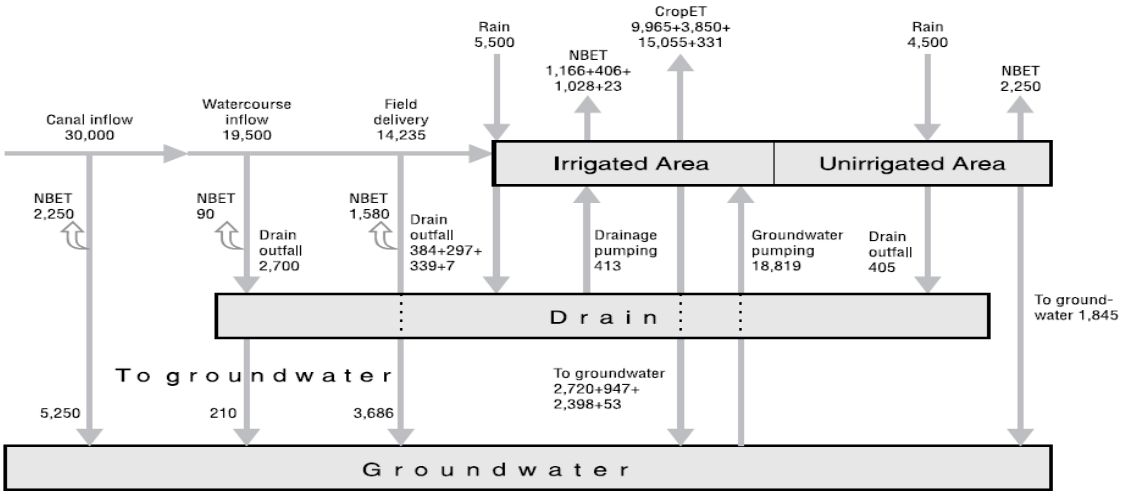


Figure 2-7 Schematic flow diagram of a water balance (Perry, 1996)

Water Balance Model at Community Level (Ratnaweera et al., 2006): This model considers water available at sub-basin level. Inflows are rainfall, surface, and subsurface flows. The outflows are surface, subsurface outflows, and evaporation. It takes into account storage within the system, both surface and subsurface, comprising surface storage, soil moisture, re-used water, and percolation. Pollution is also included as a negative component of storage. The model is presented as a box with inflows and outflows on the sketch shown in Figure 2-8.

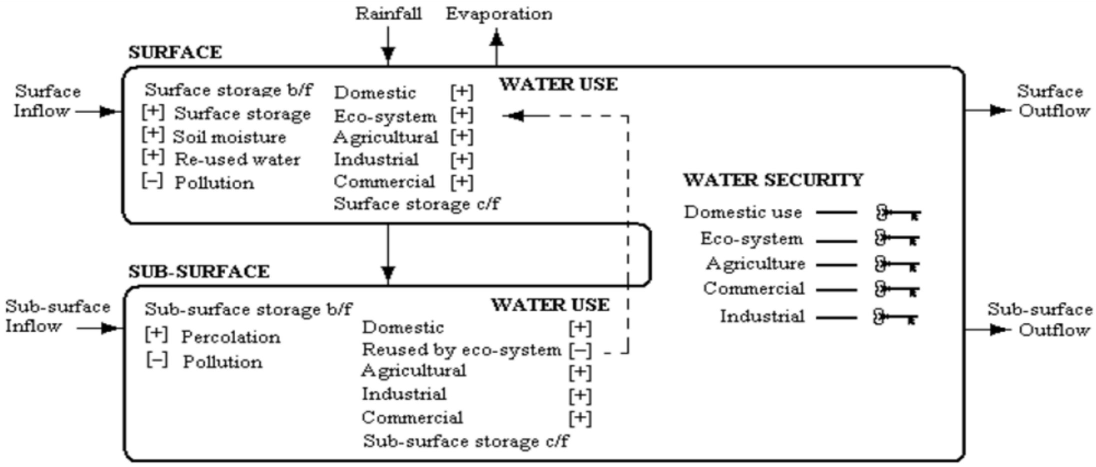


Figure 2-8 Water Balance Model (Ratnaweera et al., 2006)

The water use model (Ratnaweera et al., 2006): This model can be applied at the household level and has been proposed based on Sri Lanka context. Its inflows are surface and subsurface runoff, pipe-borne water, harvested roof water, waterways, rivers and canals, rainwater, surface and subsurface runoff, and linked to this inflows the potential needs they can meet. Outflows are surface and subsurface runoff, waterways, rivers, canals and evaporation. Subsurface storage in tanks is also included. Figure 2-9 contains inflows, outflows and storage considered by the model proposed by Ratnaweera et al.

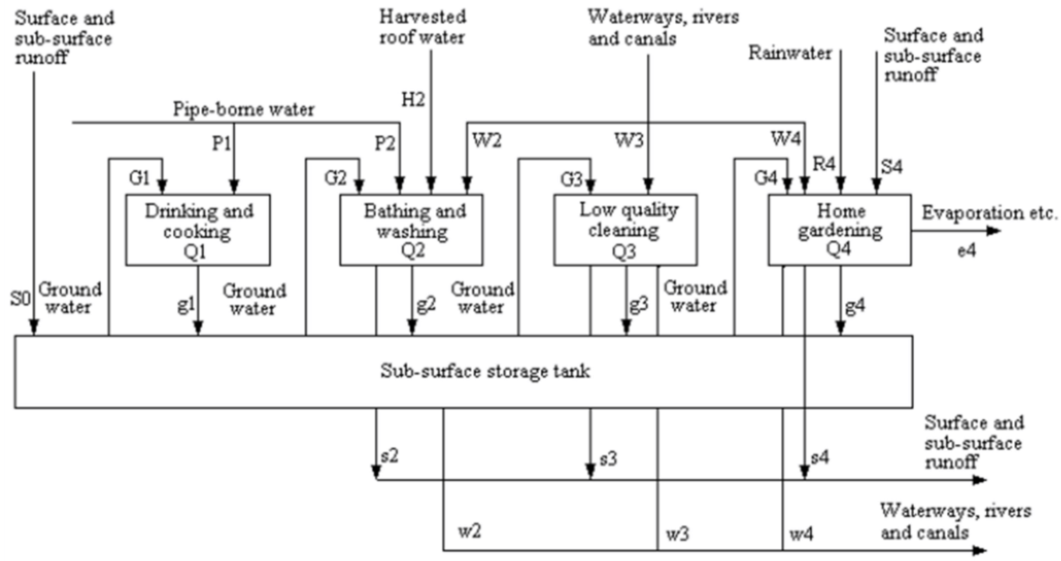


Figure 2-9 Domestic water re-use model (Ratnaweera et al., 2006)

The water use model can be considered as a multiple use model for multiple sources, since it includes a variety of potential sources that can be used for different purposes. This model is innovative in the way it “unpacks” the domestic consumption, having into account the different quality and quantity requirements of different domestic uses, such as: drinking water, bathing and washing, low quality cleaning, home gardening. This differentiation is important in water stress conditions, where multiple needs like domestic, agriculture, commerce, etc. are competing for the scarce water resources and it becomes a priority to assess water reuse opportunities.

Table 2-4 summarizes the most relevant aspects of the water balance models previously described. The Table shows that models can be applied at different scales, depending on the purpose of the study and in that sense, also the users to be included, for instance, the model develop to asses water productivity in agriculture (Perry, 1996) do not include uses such as domestic and livestock. Models for assessment water use and availability at catchment level (Rosengrant (2002) and Ratnaweera et al. (2006) for community level) are more comprehensive in the considered users. Most models include the components of the hydrological cycle (precipitation, evaporation, storage, etc.).

Table 2-4 Main components of some water balance models

Author	Scales	Inflows	Users	Outflows	Storage
Rosengrant et al. (2002)	Global level, country, region and river basins	Precipitation Inflow from transboundary basins	Domestic Livestock Agriculture Industrial Committed flow (environmental/ political)	Evaporation	Reservoir storage Soil moisture
Perry (1996)	Field and service level (irrigation)	Canal inflow Rain	Irrigated areas and non irrigated areas	Crop ET Non-beneficial evaporation/ ET, drainage, runoff, net flow to groundwater	
Ratnaweera et al. (2006)	Community	Surface inflow Subsurface inflow Rainfall	Domestic, ecosystems, agricultural, industrial, commercial	Evaporation Surface outflows Subsurface outflows	Surface storage Soil moisture Re used water Percolation Pollution (-)
Ratnaweera et al. (2006)	Household	Surface and subsurface runoff Pipe-borne water Harvested roof water Waterways rivers and channels Rainwater Surface and subsurface runoff	Mainly domestic	Evaporation Surface and subsurface runoff Waterways, rivers and channels	Sub-surface storage tank

2.7 Methodologies used to research on MUS and its interlinked subjects

This section presents some methodologies that have been used to investigate about aspects such as water use and consumption, water availability and water balances, whether or not taking into account the principles of MUS, especially in the case of water availability and water balances, since these concepts have not been studied in depth yet in MUS research. A review is carried out on the work developed, research methods, aspects regarding to data processing, analysis, sampling and limitations of the methodologies used.

2.7.1 Methodologies to research on water uses and consumption

Specific studies on water consumption for multiple uses of water were conducted by Perez Mendiguren Castresana (2003) who carried out a comparative village-case-study to look relations between livelihood activities, water consumption and performance of the water supply. Upadhyay (2005) researched on water use for domestic and productive uses and its relation with gender, income and empowerment. Katsi (2007) investigated on the impact of water-related livelihoods and efficient, equitable and sustainable use of water resources at household level in Zimbabwe. Senzanje (2008) studied main uses, water consumption per use and water productivity of different uses of small dams in a basin in Zimbabwe. Roa & Brown (2009) investigated the water needs of rural families for both, domestic and productive purposes, and water availability in relation to use in a Colombian basin. Smits et al. (2010) undertook a study on practices of multiple use of water and its impacts on the livelihoods of users, as well as on the sustainability of rural water supply services in Honduras.

There are several studies following the case study methodology, which address issues of water uses for multiple purposes and consumption. These studies were carried out under the CPWF - MUS project and are not available as journal articles, although the findings are summarized on the “Multiple Use Water Ladder” by Van Koppen et al. (2009) commented on section 2.6.1 and also in several conference papers from events such as the International Symposium on Multiple-Use Water Services (2008) (Butterworth et al, 2008).

There are a significant amount of studies focusing on water consumption itself, some of the most referenced were developed in the 1990s in African cities, and in context without household connections, especially those undertook by Whittington et al. (1990; 1991) from an economic perspective.

Most recent studies, generally analyze water consumption regarding the factors that influence it. These studies have been developed in rural and urban areas; places with different level of access to water, from household connections to fetching water; meter and unmetered households. Studies estimated consumptions directly and indirectly and water consumption has been related to a broad range of variables. Gazzinelli et al. (1998) investigated the domestic water use in a rural village in Brazil, emphasizing on the use of multiple sources by individual households, preferences and predominance of socioeconomic factors in water use, role of multiple sources in meeting water requirements of households for different uses. Bramfit et al., (1997) studied the impact of metering on water consumptions levels in Manchester. Nyong & Kanaroglou (1999) researched on the variation of daily household water consumption for rainy season and dry season in a Village in Nigeria. Trigg (2000) established peak hour factor, per capita water consumption and user´s preferences according to level of service in rural Guatemala. Adekalu et al. (2002) investigated on water-use practices, water supply alternatives and water demand in four Nigerian cities. Manzungu & Machiridza (2005) analyzed water consumption in relation to income and population density in Zimbabwe. Hadjer (2005) studied water uses, consumption and sources, and its relation to seasonality and social structure in Benin. Keshavarzia et al. (2006) established the relationships between water consumption, comparing the behaviour of low, medium and high water consumers, and established factors affecting water consumption in rural households in Iran. Mazvimavi & Mmopelwa (2006) assessed gazetted and un-gazetted rural settlements in Botswana. Lu & Smout (2008) researched about domestic water consumption in China and its relation to appliances that have the major water consumption within the household. Fox et al. (2009) studied the influence on characteristics such as number of bedrooms, architectural type, and garden presence on water consumption to assess the feasibility to use these characteristics for water demand forecasting.

The studies done under the MUS approach involved a combination of methods to estimate water consumption. Senzanje et al. (2008) used a questionnaire and data from literature to quantify volumes of water used for livestock, irrigation, domestic uses, and brick making. The data were crosschecked by observing daily activities during the study period. Smits et al. (2010) used participatory tools such as community mapping, wealth classification and focus group discussions, in combination with a household survey, consumption measurements and technical reviews of the systems to establish water consumption from a number of domestic and productive uses. Finally, Roa & Brown (2009) conducted a farm survey relevant to local farming practices and carried out direct measurements of water domestic consumption in 30% of the houses in a micro-watershed in a nine months period. They established disaggregated water consumption for activities such as toilets, personal hygiene, cooking and drinking, dishwashing, laundry, and household chores. Water use for productive activities such as crop irrigation, stable cleaning and coffee processing was measured in selected - representative households of the dominant crop and livestock types within the micro-watershed.

For general studies on water consumption, different methods have been used. Household surveys with semi-structured questionnaires were used by Manzungu & Machiridza (2005) and Nyong & Kanaroglou (1999). Nyong & Kanaroglou (1999) asked about water availability and water use in two household surveys, one during rainy season, and the other during dry season, using differentiated questionnaires by gender. Perez Mendiguren Castresana (2003) and Katsi (2007) combined semi-structured household interviews with group discussions. Hadjer (2005) used observation during a six months period, where selected households were visited once every month from 6 a.m. to 9 p.m., and all water-related activities were recorded with time of day, person, purpose, etc. Adekalu et al. (2002) combined questionnaires, in-depth interviews and personal observations, while Ezeji & Smout (2009) used questionnaires together with focus groups and observations. Upadhyay (2005) adopted the same approach that Ezeji & Smout (2009), but included measurements of daily water use for livestock in drinking, bathing, and cleaning.

Gazzinelli, et al., (1998) recorded water contact activities observed at 24 communal sites for 7 consecutive days between 7:30 a.m. and 5:30 p.m. Households with their own water supply were interviewed twice a day during the 7-day study about the quantity of water they had used during the day for different activities. In addition, the female heads of 4 households were asked to record on forms the quantity of all water used for individual activities carried out in a 3-day period. Focus group discussions, unstructured interviews with key informants and a household survey complemented the study.

Fox et al. (2009) used data from daily household demand covering a period of 2 years and established relations with household physical characteristics. Keshavarzia (2006) used daily water consumption data for a 5-year period, complemented with a questionnaire addressing domestic water use patterns, and individual household characteristics. Bramfit et al., (1997) used a self-administered questionnaire followed by water usage monitoring over 7 consecutive days and use water usage diaries where frequencies of use, time of use and water flows were recorded to quantify consumption for different uses.

In relation to the sampling strategy adopted, in some studies, especially those including estimations through direct measurements the households were those that show willingness to participate as in the case of Lu & Smout (2008) who surveyed households of family and friends, and Bramfit et al. (1997) who contacted people which belong to different organizations. In most studies, households were selected under a simple random sampling (Manzungu & Machiridza, 2005; Keshavarzia et al., 2006; Katsi, L., 2007). In comparative village case studies, as those from Perez Mendiguren Castresana (2003) and Smits et al. (2010), villages were purposive selected according to the objectives of the study, but in the selected villages, household questionnaires were conducted in randomly selected households. The study of Nyong & Kanaroglou (1999) adopted a stratified random sampling and Roa & Brown (2009) selected participant households under an equally distribution in the micro-watershed as upper, mid, and lower section. They conducted the questionnaires in 30% of the households. The sample of Senzanje et al. (2008) constituted 7.5%, 6%, 10% and 7% of the households served by 4 dams.

From the papers analyzed, 7 commented on the data analysis and from those, 4 highlighted the use of the Statistical Package for Social Sciences (SPSS) for this purpose (Bramfit et al., 1997; Manzungu & Machiridza, 2005; Keshavarzia et al., 2006; Senzanje et al. 2008). The studies that collected data from meters used uni- and multi-variate analysis to find statistically significant relations (Fox et al., 2009). Other statistics cited were frequency, percentage, means, standard deviation, one-way analysis of variance, Pearson correlation coefficient and discriminant function analysis (Keshavarzia, A. et al., 2006); multiple linear regression (Gazzinelli, A. et al., 1998) and one-way analysis of variance (Senzanje et al., 2008)

Some limitations stated on the studies are the necessity to accompany studies based on meters records with household surveys in order to enrich information and prepare better correlations (Fox et al., 2009); and the need to establish relations between water consumption, climatic variations (seasons), and socioeconomic aspects (Hadjer, 2005). Others highlighted problems to achieve the targeted number of consumption data due to the limited availability of records and problems with the targeted interviews because some respondents did not return questionnaires or were not available during the study visits (Manzungu & Machiridza, 2005). Lu & Smout (2008) also discussed limitations on the sampling method and small sampling size. Other authors explained the need for more interdisciplinary approaches that combine hydrological, climatological, economic and anthropological findings (Hadjer, 2005; Senzanje et al., 2008). Senzanje et al. (2008) considered important on MUS studies not only research focused on the demand side of water for various uses, but also to look at the supply side, and on how to match supply with demand.

2.7.2 Methodologies to research on water availability and water balances

Water availability on MUS research has been studied mostly through qualitative methods such as household surveys alone (Nyong & Kanaroglou, 1999; Adekalu et al., 2002; Perez de Mendiguren, 2003; Machingambi & Manzungu, 2003; Mazvimavi & Mmopelwa, 2006), or combined with focal groups or in-depth interviews (Upadhyay, 2005; Gazzinelli et al., 1998; Kusiluka et al., 2004), asking about people´s perceptions on aspects such as available sources, reliability, access and quality. Sometimes comparisons have been carried out in relation to seasonal changes (Mazvimavi & Mmopelwa, 2006); Gazzinelli et al., 1998; Nyong &

Kanaroglou, 1999), gender (Upadhyay, 2005), socioeconomic status (Hadjer, K., 2005) and accessibility (Machingambi & Manzungu, 2003; Perez de Mendiguren Castresana, 2003; Kusiluka et al., 2004; Upadhyay, 2005). Sometimes these perceptions were combined with technical inspections, which involved measurements at the storage tanks (Smits et al., 2010).

Few studies have adopted a quantitative approach such as Roa & Brown (2009) which measured the quantity of water from the primary source of water for the micro-watershed studied, taken 55 dates during 4 months, and combined it with precipitation and downstream flow. Other approach was adopted by Harrington et al. (2009) who used water accounting tools to establish how water availability, access and quality, affect rural livelihoods, doing a comparison between large basins: Ganges, Indus, Karkheh Limpopo, Mekong, Nile, São Francisco, Volta and Yellow.

Studies from the agriculture sector and water management at catchment level have been focused on improving water productivity (Droogers et al., 2000; Mutiro, 2006; Vazifedoust et al., 2007; Ahmad et al., 2009), or gain a better understanding on the hydrological cycle and partitioning process (Jewitt et al., 2004; Hope et al., 2004; Makurira et al., 2007). In some of the studies, models such as SWAP (Droogers et al., 2000; Vazifedoust et al., 2007), ACRU (Jewitt et al., 2004; Hope et al., 2004) and HYLUC (Jewitt et al., 2004) have been used. In other studies, different components of the hydrological cycle have been measured (Vazifedoust et al., 2007; Mutiro, 2006). In the studies where models or field measurements have been carried out, estimations have been based on water balance concepts.

The different studies adopted different approaches to acquire the information required for the water balance equation dependent on the research objectives. When components of water balance were measured, studies were at field scale. Precipitation data was obtained from climatic stations (Ahmad et al., 2009; Jewitt et al., 2004; Vazifedoust et al., 2007) or directly by installing rain gauges (Mutiro, 2006; Droogers et al., 2000; Makurira et al., 2007). Evapotranspiration was generally calculated from equations that use climatic data (Droogers et al., 2000; Jewitt et al., 2004). In other cases, evaporation was measured from the soil by use of lysimeters constructed on site (Makurira et al., 2007). Mutiro (2006) measured transpiration using a sap flow meter. Flow measuring devices were used to estimate runoff (Makurira et al., 2007). Soil data was obtained from existent soil maps (Droogers et al., 2000) or soil maps and land use maps were prepared with information from questionnaire surveys (Ahmad et al., 2009). Soil properties were obtained from laboratory analysis (Vazifedoust et al., 2007; Mutiro, 2006) or LANDSATTM remotely sensed images (Jewitt et al., 2004) and GIS software (Jewitt et al., 2004). Crop patterns have been obtained from questionnaire surveys (Ahmad et al., 2009) and existent databases (Droogers et al., 2000). Infiltration was usually calculated from the water balance equation, but Mutiro (2006) carried out infiltration tests using a double ring infiltrometer.

2.8 Gaps in research

The demand side in MUS studies has been addressed especially using qualitative methods. The CPWF – MUS project produced several studies indicating water demands for multiple purposes, although, in most cases, those demands have been quantified asking people directly their water consumption trough surveys. Therefore, as figures exists, there is still the necessity to combine qualitative and quantitative methods to understand demands for the different uses of water which people have, as a previous step to find out how to integrate them technically (Nguyen-Khoa et al, 2008). This requires research on how to assess demand, according to people livelihoods, and integrate knowledge and tools from different disciplines.

While most of the MUS studies have addressed the demand side, water availability (the supply side) has been generally ignored, except for the work of Roa & Brown (2009); Harrington et al, (2009). The focus has been on water sources (what sources people use) rather than on water availability (how much water people may have access to). Therefore, knowledge on the supply side on MUS studies is required (Nguyen-Khoa et al, 2008; Sezanje, 2008). For instance, how to incorporate knowledge on the water cycle and its interactions with human systems, introducing the green water branch to the traditional process of planning for the blue water branch, recognizing the importance of rain for poor farmers.

So far, many of the findings on MUS still appear as statements on what should be done and much remains to be investigated on how to translate these principles into planning tools, policies or real interventions (Smits et al., 2008), except for the case reported by Mikhail (2010) who documented the experience of MUS systems in Nepal. Thus, research is required to know how to integrate the mandates from different sectors and institutions, to introduce the different water uses from people in planning; and what are the most suitable technologies, institutional and financial arrangements to put in place MUS.

Another gap, since some studies have shown that wealthier households within communities had the highest benefits within some MUS systems (Smits et al.,2010; Mikhail 2010), is how to achieve equity and how the poorest can be particularly targeted (Smits et al., 2008). Therefore, if within a system all have virtually the same level of service, some questions that need to be solved are: Which are the water needs of different types of users within a system? Who are those that use more water? What are the determinants for them to use more water than others? How to incorporate these diverse needs and interests in the design and operation to achieve equity and sustainability in service provision?

In general, despite all the available literature, abundant or scarce, in each of the aspects above, the South American context, and the Colombian context, have not been sufficiently documented. This context has different features on the demand and supply sides, where surface gravity fed systems with household connections, rainfed agriculture, higher per capita demand for domestic uses, and different technological alternatives to secure access, may represent different demand characteristics that need to be researched.

Hence, this study seeks to fill some of these gaps in the documentation of the demand and supply of water, in terms of green water and blue water in a MUS system in Colombia, combining the use of quantitative and qualitative research methods. Issues of equity are addressed as well, aimed at looking to households which different consumption levels.

2.9 Summary

This literature review has addressed some of the topics underlying the concept of Multiple Uses of Water, such as poverty and its determinants, productive activities and livelihoods and the relationship of all these with access to water. Approaches in response to the challenges of poverty reduction and lack of water universal coverage, which have been proposed, looking for interventions that meet more effectively the needs of individuals, ensuring sustainability, has been also studied here (SLA and DRA).

The review has shown how the concept of Multiple Uses of Water emerges from these ideas, but also, the challenges it posses to integrate knowledge from various disciplines and efforts of various sectors, so that its implementation requires from professionals to develop and implement innovative approaches for which they may have not received training. Therefore, the review focused on understanding multiple demands on water (i.e. domestic, agricultural, livestock) traditionally addressed separately by the various actors in development and included the supply side, with the study of blue water and green water; the latter, a new "paradigm" for water resource management. This review was done looking for an understanding on the hydrological cycle in their interactions with the human system.

The need to integrate supply and demand, led to look into the concepts of water balance and water budgets as tools to understand and quantify these interactions. Principles and applications of these tools in particular contexts were reviewed, showing its flexibility to be used in accordance with the level of analysis, research objectives and available information.

Finally, it was identified how the above topics have been studied in the past, not only from the perspective of MUS, but also from other approaches and disciplines. Such a review was a key element to formulate the methodology of this particular investigation, taking into account the strengths and limitations included in previous studies.

3 THE CASE STUDY AREA

The introduction to this document presented general aspects of Colombia and its rural area, people´s productive activities, livelihoods, water services provision, and the poverty situation that exists, which together with inequality are major challenges for the country (World Bank, 2010). That presentation was intended to place the reader in the general context in which this research has been proposed, and the relevance of the Multiple Uses of Water supply systems for rural Colombia.

This chapter presents an overview of the specific area selected as a case study, the villages of *La Palma, Tres Puertas and Buenvivir,* and the system that provides water to them, *La Palma Tres Puertas* water supply system. In addition to general aspects, this chapter includes information directly related to the issue of Multiple Uses of Water in this region, since in this place, two studies relevant to this investigation were conducted previously (Cinara, 2006; Ospina, 2009). The results from these studies and the literature review were the basis to decide on the approach for this research.

3.1 Location

The water supply system of *La Palma Tres Puertas* serves the villages of *La Palma, Tres Puertas and Buenvivir*, located in the municipality of *Restrepo* in *Valle del Cauca Department* (Colombia). The territory is mainly mountainous with small valleys in between, to the eastern slope of the western Andes Range (Ospina, 2009). The villages are characterized by a dispersed settlement pattern with low population density, occupying an area of 15.5 km^2 (Alcaldía de Restrepo, 2004), that covers the settlements of *Chontaduro, Tres Puertas, Buenvivir, La Palma, Ventaquemada, Colegurre, Monteredondo* and *El Agrado*. The settlements belong to the villages. The general location is shown in Figure 3-1.

3.2 Climate

Climatic station *Julio Fernandez* is located within the study area (Altitude 1381 m, North Latitude 3° 49´ and West Longitude 76° 32´). This station is managed by the *Centro Internacional de Investigaciones del Café (Cenicafé*), which operates a Weather Service to study and determine the climate of each of the coffee regions in Colombia. In *La Palma Tres Puertas, t*emperatures range from an average minimum about 17°C and a maximum of about 25°C, median temperatures are about 20°C. The precipitation has a bimodal behaviour, with two rainy and two dry seasons, and annual precipitation ranges between 880 and 1392 mm / year. Sunlight oscillates from 130 – 180 hours per month, and humidity varies from 80 to 85% (Cenicafé, 2010).

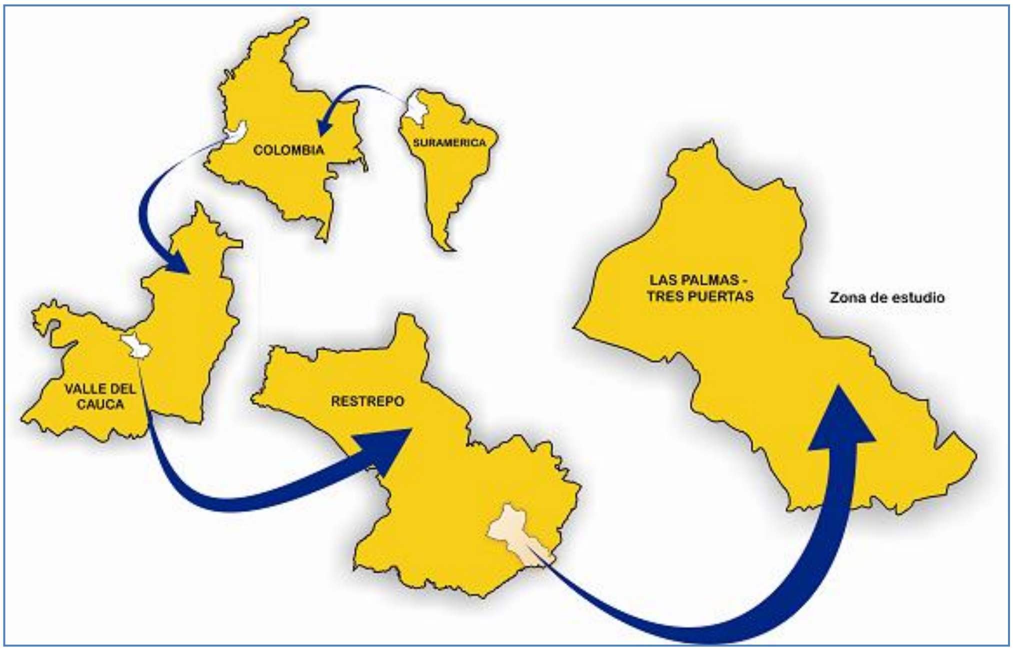


Figure 3-1 Location of the study area (Ospina, 2009)

3.3 Surface sources

The study area is part of *Dagua* watershed, basin of *Rio Grande*, sub-basin of *Aguamona* stream. The water system is supplied by two smaller streams that converge on *Sabaletas* sub-basin. Those are locally known as *La Tobón* and *Sinaí.* The surrounding area of *La Tobón*, is protected and covered by natural vegetation, but around *Sinaí,* there are extensive crops of commercial forest on species such as Pine and Eucalyptus (Cinara, 2006).

The water from the two streams according to analysis undertaken at the storage tank and the distribution network, presents quality problems due to the presence of significant levels of Total and Faecal Coliforms and high levels of Colour and Iron, higher than the values recommended for drinking water by the World Health Organization (WHO) (Ospina, 2009)

3.4 Geology

The villages are located on a volcanic outcrop (Kv), which includes diabasas with ophite structure, plagioclase crystals in augite and thin layers of “chert”. The horizon A is made from laterite, with thicknesses ranging from 1 to 30 m, and in some cases reaching up to 50 meters. Horizon B is several meters thick, made from hard soil, “red earth”, from reddish yellow to cream, silty-clay-sandy with bowls of different sizes made from diabase; in the structure, spheroidal weathering is well developed. Horizon C is composed of relatively fresh rock, massive, very hard, dense, sometimes broken, badly broken or even as tectonic gap (Alcaldía de *Restrepo*, 2004). There is no evidence of groundwater use by people in the region.

3.5 Soils and Land use

Soils are known as Sevilla Association (SV), originated from volcanic ash deposited on clay, as result of altered diabase. These soils are deep, well drained and slightly to moderately eroded (Alcaldía de *Restrepo*, 2004). Figure 3-2 shows a landscape of the study area.

Figure 3-2 Landscape of the study area

The land is suitable for crops and forest, according to the slopes, which range from 12 to 50%. The vegetation has been severely affected, causing losses of forest in watershed areas and micro-catchments. Hillside areas are counted as the most affected because of the increase of the livestock frontier and the introduction of alien species such as Eucalyptus and Pine trees for industrial purposes (Ospina, 2009). Moderate to severe or very severe erosion affects more than 70% of the area in both, La Palma and Tres Puertas (Alcaldía de Restrepo, 2004). Most of the land is dedicated to crops and grass as shown in Table 3-1, which contains the existing coverage with their current uses.

Table 3-1 Coverage and current land use (Alcaldía de Restrepo, 2004)

Coverage	Current land use	Area (Km^2)	Proportion (%)
Crops	Agriculture	4.4	28.39
Grass	Livestock farming	7.31	47.16
Natural Forest	Protection	2.94	18.97
Bamboo Forest		0.05	0.32
Planted Forest		0.17	1.10
Stubble		0.63	4.06
Total		15.5	100

3.6 Population

The population of the villages supplied by the water supply system is about 1800 inhabitants, with an average household size of 4. In most cases, the family income depends on the head of the family. People livelihoods are related to livestock and animal husbandry. By 2005, 37% of household heads were day-labourers and 22% farmers, the rest were employees, retired, merchants or self-employed. The employees included people who administered some bigger farms. 40% of people had income levels from US$ 90/month to US$180/month. Day-labourers had one of the lowest income levels and property managers earned the higher revenues (Cinara, 2006). Figure 3-3 presents some local farmers of *La Palma* carrying their pineapple harvest.

Figure 3-3 Farmers carrying their harvest

3.7 Infrastructure

Water service has 100% coverage. There is no sewerage, streams and small surface water sources receive wastewater discharges from households, although it is estimated that about 40% of the households have septic tanks. The electricity service has nearly 100% coverage. Most of the houses have cell phones. There is no solid waste collection service, leading people to manage solid waste at their homesteads. Each village have a school, communal house and there is a primary health care centre for the three villages.

3.8 The water supply system

3.8.1 System description

The Committee of Coffee Growers[4] built the supply system about 35 years ago. It was designed to serve 150 users from *La Tobón*. Presumably, the increase in population during the years of operation and lack of investment in the system led to an insufficient capacity. In 2003, the 400 existing users received water two times a week. In 2004, with funding from the PAAR Program, an intake, a transmission pipe from another stream, the *Sinaí*, and a new storage tank to receive water, now from the two streams were built. It was expected to have

[4] The Colombian Coffee Growers' Federation is a farmers' organization, established in 1927, responsible for the social well-being of Colombian coffee growers. Over the years, the Federation has established a number of subsidiary institutions, including a research institute (Cenicafé), a capital fund and a merchant marine fleet (Bentley & Baker, 2000).

permanent continuity of service. However, the problems persisted and continuity only increased to four times a week. The PAAR team felt that the level of service did not improve, as the community "*wasted water on crops and pigs"* (Cinara, 2006).

Today, the service is received for the 437 households on average once a week, which leads to a complex operation of valves and shifts and thus, families have implemented different adaptation strategies.

The water supply systems consists of two intakes and settle tanks that bring water from *La Tobón* and *Sinaí* to a centralized tank of about 160 m^3 capacity. There is no metering for the total water delivered. The distribution network is PVC pipe and consists of nine main branches in pipes of diameters ranging from 3 "to ¾". Households have micrometers, whose readings are carried out every two months by the caretaker. During the fieldwork period for this research, a packaged drinking water plant was being installed, intended to provide drinking water for the first time to this community.

3.8.2 Management issues

The water supply system is operated by an administrative board legally constituted under Colombian law, consisting of representatives elected by Community Action Boards of the beneficiary villages. The Board is composed of Chairman, Treasurer, Fiscal, Secretary, and Vowels for each of the villages. The Board hires a caretaker, who is in charge of the operation and maintenance of the system. The bulk of the households have low participation in the management of the system, there is a low attendance of people to Assemblies. The system has no manager. The General Assembly of Delegates practically does not exist, the Board do not hold meetings as is required by the Statutes, and the Chairman also holds the majority of the administrative tasks (Cinara, 2006). The Board must be renewed every two years, but this does not happen due to lack of meetings of the General Assembly of Delegates and Members.

Since 2007 there is differentiated tariff according to water consumption. People pay 2,5 US$ for 25m^3 every two months and beyond that volume, each m^3 has a charge of 0,16 US$. No investigation was made to elicit the criterion for the establishment of these values.

3.8.3 Uses of water

According to Cinara (2006b) about 80% of people in *La Palma Tres Puertas* developed at least one productive activity, animal husbandry, agriculture or both. Most important crops are coffee, pineapple, beans, maize and some vegetables. People raise mostly chickens, pigs, and cows. Figure 3-4 shows some examples of the productive activities developed in the area. To the left, a plot with maize, and to the right a local woman milking a cow.

Figure 3-4 Productive activities

The water supply system is used almost exclusively for all domestic uses (98%) and for raising of animals (96%). It is used to a lesser extent for crops, since the main crops such as coffee and pineapple do not require water for irrigation. Water is required for coffee processing, and for preparing solutions of fertilizers and fungicides. Beans, corn and vegetables are planted according to the time of year, thus those depend mainly on rainfall. In any case, when water is needed for agricultural uses it is obtained from the water supply system (Cinara, 2006; Ospina, 2009).

Cinara (2006) found that by 2005 about 30% of users had water consumption levels below 40 m^3/every two months, equivalent to the Colombian standard for domestic uses (RAS – 2000); 53% had a consumption between 41 and 100 m^3/every two months, and 17% higher than 100 m^3/every two months. Due to the service intermittence, each farm had tanks for storing water: 54% under 3 m^3, and 53% greater than 3 m^3. Water consumption levels and household storage were directly related (Cinara, 2006). Figure 3-5 shows examples of storage units at the household level. The type of units usually depends to the economic capacity of the family.

Figure 3-5 Storage units at the household level

A study by Ospina in 2009, where 62 houses were surveyed, corresponding to 39% of the population surveyed in 2005 (154), which have both, livestock and crops, provided the results listed below:

- In this segment of the population 54% of the planted areas were under 3200 m^2 and 21% were under 6400 m^2. Coffee and pineapple were 51% and 12.6% of planted areas respectively. These crops were grown throughout the year. Crops which require irrigation such as beans and maize were present in many homesteads, but none exceeds 1 hectare;
- 71% of respondents did not irrigate, 18% used hose or bucket and 5% back pump. The months with higher consumption of water were the dry season June, July and August;
- 51% of households had chickens and 23% pigs. 9.5% of respondents had commercial farms;
- estimations of water demand for this segment of population, taking into account domestic and productive activities based on survey information, conclude that water demand for crops that require supplemental irrigation was 7.57 l/s, for the critical month, June; pesticide application was negligible, as well as coffee processing assuming the "tank-bath" system. For livestock, the total demand was 0,09 l/s. For domestic activities the demand was 0.49 l/s, using the 150 lpcd, suggested by RAS - 2000

The purpose of the study above was to estimate the water demand of small-scale agricultural activities in terms of a per capita allocation for the design of supply systems. This study was focused only on the demand side and did not take into account water availability. Due to its particular objectives, the sample was not randomly selected and did not include the whole spectrum of categories of households within the system.

4 METHODS

After presenting the literature review and the relevant aspects of the study area, this chapter describes how this research was conducted. It includes the methods used to collect the data required to develop the three proposed objectives:

- To characterize groups of households within a MUS system according to aspects related to poverty, productive activities, livelihoods and access to water
- To measure different components of the domestic water per capita consumption in households within a MUS system
- To propose balances at the system and household level, including water demand for multiple uses and water availability, considering blue water and green water.

Aspects of data management, data analysis, and the limitations of the methods used are also addressed. The chapter is structured according to the order of the objectives and for each objective, the methods have been described according to the chronological order in which they were applied.

4.1 Characterization of groups of households within a MUS system according to aspects related to poverty, productive activities, livelihoods and access to water

This objective was addressed by using two sources of information. In one hand, household´s average water consumption, and on the other hand, water use related characteristics of the households based on information from a survey.

Household´s average water consumption: average water consumptions of households were obtained from readings of the household´s meters installed by the Water Committee. The caretaker undertakes water consumption measurements every two months for the customers of the water supply system. Within the system, 430 customers are domestic and 7 are institutional. Water consumption records for the domestic customers in m^3 from January 2009 to December 2009 (6 records – 1 record every two months) were provided to the author in hard copy by the Water Committee. This information was transferred to an Excel spreadsheet.

Average water consumption for each household was calculated from available valid records for the year 2009. For this purpose, the data were cleaned to remove households who had records with anomalies. Households with 3 or more valid records from the possible 6 records were kept within the group to perform the analysis. A sensitivity analysis indicated that in this case, to use potential methods to complete missing data (Useche & Mesa, 2006) will distort the average water consumption or otherwise will not provide any benefit for the water consumption average calculation. Invalid records were considered as no reported value, reported values from 0 to 3 m^3 or a reported negative value. From this cleaning process, 117 households were taken out from the group of analysis as shown in Table 4-1 since their average water consumption was not possible to be calculated under the criteria set.

Table 4-1 Data cleaning process

Category of households	Number of households
Households who lack of the full six records	86
Households who lack 5 records	14
Households who lack 4 records	17
Total households which lack more than 3 records	117

According to the caretaker, this situation occurs when farms have been abandoned and also where meters are not working and people take time to replace them. The cleaning process resulted in a group of analysis of 313 households. For this group, mean bimonthly water consumption, standard deviation and standard error were calculated for each household. These descriptive measurements were calculated for the complete data set as well.

Household survey about household water use characteristics:

Sample frame and sample size: The group of analysis previously defined was the sample frame for the household survey. It represented 73% of the served population and included households from all the 8 villages covered by the system in a wide range of water consumption, ranging from an average of 8 to 755 m^3/ every two months.

From the sample frame, a stratified sample was defined. The population was divided into "average bimonthly household water consumption" strata. The range of water consumption of each stratum was defined based on previous studies developed in Colombia (Cinara, 2006, Cinara, 2007a; Cinara, 2007b). The author defined these strata assuming that in the first stratum (4 – 20 m^3/every two months) households use water from the system only for domestic uses. In the second stratum (20 – 80 m^3/every two months) households develop small-scale productive activities that contribute to family income; and in the third stratum (> 80 m^3/every two months) households develop commercial activities that depend on water. It is important to keep in mind this differentiation, since the results, discussion and conclusions were prepared in terms of these strata.

This type of sample, the stratified sample, was selected due to it enhances the likelihood of the proper representation of strata in the sample (Bryman & Cramer, 2001).

Table 4-2 shows the strata and the descriptive measurements of each. The descriptive measurements were calculated by using statistical formulas available on the Excel package.

Table 4-2 Descriptive measurements for the stratified population

Parameters	Average water consumption		
	Stratum 1	Stratum 2	Stratum 3
N	37	205	70
Arithmetic mean (X)	14	46	147
Median (Me)	14	46	126
Mode (Mo)	13	34	98
Variance (S^2)	13	254	9060
Standard Deviation (S)	4	16	95
Variation coefficient (V.C.)	0,26	0,34	0,65

From the population on each stratum a simple random sample was calculated, giving to every household an equal probability of inclusion (Bryman & Cramer, 2001). The sample size was estimated by using the equation for Sample Size to estimate the mean for Finite Populations (Fernandez, 2001), given by the Equation 4-1:

$$n = \frac{N * Z_\alpha^2 * S^2}{d^2 * (N-1) + Z_\alpha^2 * S^2}$$

Equation 4-1

Where

n is the sample size

N total population

Zα: Coefficient for a fixed confidence level

d is the precision desired to estimate the parameter or width of the confidence interval

S^2 is the variance

Different values of confidence level (Zα) and precision (d) were introduced on the Equation 4.1 to conduct a sensitivity analysis to establish the sample size for each stratum. The sensitivity analysis appears in Table 4-3.

Table 4-3 Sensitivity analysis for sample size for the Strata

d / Zα	**Stratum 1**					**Stratum 2**					**Stratum 3**				
	$1m^3$	$2m^3$	$3m^3$	$4m^3$	$5m^3$	$1m^3$	$2m^3$	$3m^3$	$4m^3$	$5m^3$	$1m^3$	$2m^3$	$3m^3$	$4m^3$	$5m^3$
80%	14	5	2	1	1	138	69	38	23	15	70	69	67	65	63
85%	16	6	3	2	1	148	80	46	28	19	70	69	68	66	64
90%	18	7	4	2	1	158	93	56	35	24	70	69	68	67	65
95%	22	10	5	3	2	170	112	71	47	33	70	69	69	68	67
97,5%	24	11	6	4	2	175	122	81	55	39	70	70	69	68	67
99%	27	14	8	5	3	183	138	98	70	51	70	70	69	69	68

From the information on Table 4-3 the sample size was chosen having into consideration a value that allow for firm conclusions, but at the same time considered the resources available to conduct the fieldwork. The sample size chosen include a confidence level of 95%, considered acceptable for the bulk of social research (Bryman & Cramer, 2001). A precision of 2 m^3 was also selected. Table 4-4 presents a summary of the sample size selected criteria to conduct the survey.

Table 4-4 Estimated parameters and sample size for the strata

Parameters	Stratum 1	Stratum 2	Stratum 3
N (sample frame)	37	205	70
Variance (S^2)	13	254	9060
Zα (Confidence level)	95%	95%	95%
d (precision)	2 m^3	2 m^3	2 m^3
n (sample size)	10	112	69

With the obtained sample size, a random process was conducted for household selection to reduce the possibility of bias in the selection procedure (Bryman & Cramer, 2001). In this case, as the sample frame was part of the Water Committee customer list, it was organized according to villages and location of households within the villages, the random process was adopted to eliminate the inherent ordering on the list to avoid distortions. Excel random tool was used to obtain random numbers to select from the list of customers.

For the randomly selected households, a test was conducted to check if the mean of the household's water consumption on each stratum was within the confidence interval of the population (X ± 2 m^3). The test was positive for all the stratum, confirming that the sample size was representative of the population for the selected confidence interval (95%) and precision (2 m^3). 35 additional households were randomly selected and included within the list of households to be surveyed, allowing for replacement, in case there was no people at the households, people refuses to answer or any other situation at the moment of the team visit.

Household survey: To characterize households according to aspects related to poverty, access to water and livelihoods in a MUS system, a household survey was formulated. A questionnaire was designed including factors which affect water consumption in *La Palma Tres Puertas*, informed by findings from the two preliminary studies carried out in the locality (Cinara, 2006 and Ospina, 2009), and the literature reviewed on the topic. Those factors are listed below:

- Household size
- Total area of the household
- Type of sanitation system
- Cropped area by type of main crops

- Number of animals per species
- Storage capacity
- Sale of products from the farm
- Frequency of supply
- Occupation of household head
- Monthly income level

The questionnaire also included questions to be used by two more research studies in *La Palma Tres Puertas* conducted by undergraduate students. The undergraduate research projects were also regarding MUS. One study was undertaken by one undergraduate student in Economics about willingness to pay for improving the service continuity. The second study was addressed by two Topographic Engineering students about changes in water and land use in the area in a period of 5 years. Students formulated their own questions and the author compiled a final version of the questionnaire including the questions required for the three studies. This version was checked by the students and from professionals of the Integrated Water Resource Management (IWRM) at Cinara, Universidad del Valle, organization funding the research. Appendix A includes the questionnaire used.

Selected households were located on a water supply map provided by the Coffee Growers Association. The fieldwork team consisted of the four students developing research projects, two more undergraduate students and one junior professional from Cinara. Based on the sample frame and the resources available, a 3 days fieldwork was planned. Before going to the field, the author conducted a meeting with the team members to explain the objectives of the three research projects, show the study area, the survey plan, review, practice and adjust the questionnaire, discuss logistic issues, etc.

The survey was carried out for three days from 8:00 to 20:00, covering the 3 villages and its sectors. The schedule of interviews was up to 20:00 due to security reasons. Household members more than 18 years old were targeted as respondents for the interviews. The objectives of the interview were explained in simple language to the interviewees and informed consent was asked. Respondents were aware about their right to refuse to answer questions or withdraw from the interview at any time, and about the confidentiality of the information. Figure 4-1 presents one of the members of the fieldwork team interviewing a housewife in *La Palma* village.

Data management: Every day after the fieldwork finished, the author checked the surveys conducted for each team member, looking that all questions were answered and that answers were understandable. Records regarding households where the survey could not be carried out for different reasons were kept. An Excel spreadsheet was prepared to transfer the collected data. Codebooks with full variable and value labels were created to process the outcomes from the questionnaire (University of Edinburgh, 2010). A new version of the dataset was created everyday with the correspondent date and backups with the information were prepared on data traveller disks. The number of filled questionnaires by stratum was checked every day to find out the progress to achieve the sample size.

Figure 4-1 Fieldwork team member interviewing a local woman

Data analysis: Statistics were used to describe the basic features of the data in the study. Tables and graphics were prepared to characterize households of the water supply system according to the variables of the survey, having into account the strata defined by average bimonthly household water consumption. Based on the literature review, strata were characterized on ten variables grouped in three categories:

- *Poverty:* household size, total area of the homestead, occupation of household head, income level
- *Productive activities and livelihoods:* cropped area and livestock
- *Access to water:* location, frequency of supply, storage tank capacity and perception of impact due to service intermittence

Results were discussed in terms of the literature review and the research questions, establishing principles, relations, generalizations; commenting on correlation faults and comparing this information to previous work developed by other authors in relation to these topics.

Limitations

- People which do not have more than three valid meter records were not part of the sample frame, therefore there was people receiving water from the water supply system that due to problems with the meter could not be included within the study
- Bimonthly records were available instead monthly records. This situation limited a more detailed analysis; for instance, between wet and dry season consumption, since the

bimonthly periods of readings do not match strictly with the bimodal climatic behaviour in the study area

- It is possible people may not have provided accurate information. Many interviewees were afraid of the purposes of the survey, despite the team were keen to explain the academic aim of the activity and the confidentiality of the information. People were very suspicious since the questionnaire included questions about people assets (land, livestock), income levels and willingness to pay for improvements on the water service[5], etc. Various interviewees also remembered that during 2005, other students developed similar interviews, and according to them, after those studies, tariffs were increased.
- At the end of the fieldwork, a smaller number of households were interviewed on stratum 2 and 3 in relation to the calculated sample. It reduced the precision of the information on these strata. The main causes for this situation were that some households were abandoned, households were used for recreation purposes and habited just on weekends; at the moment of the visit inhabitants were working out; households could not be found by the team members, or the access was very difficult. Other two situations that limited to achieve the sample size were that some people refused to answer the questionnaire due to fear of the purposes of the information; and in other cases, some people recommended the team members not to visit some households, due to the risk to find aggressive people.

  The situation described above, was more critical for the third stratum, since the sample size (69) was almost equal to the population (70) and just 32 people were interviewed. These problems appear on more than the 35 spare households selected within the sample, and since the stratification did not match with the location of the households and the scattered of the area, it would be complicated and costly to find out a way to replace the households to achieve the sample within the available time to conduct the fieldwork. The final sample size per stratum and their statistical parameters appear in Table 4-5.

Table 4-5 Final parameters and sample size for the strata

Parameters	Stratum 1	Stratum 2	Stratum 3
N (sample frame)	37	205	69
Variance (S^2)	13	254	9060
Zα (Confidence level)	95%	95%	95%
d (precision)	2 m^3	2 m^3	2 m^3
n (sample size)	10	112	69
n_R (real sample size)	17	84	33
d_R (real precision)	1 m^3	3 m^3	24 m^3

5 For the purpose of the undergraduate researches

4.2 Measurement of different components of domestic water per capita consumption in households within a MUS system

The second part of the fieldwork was to monitor water usage in some of the households served by *La Palma Tres Puertas* water supply system during dry season, the critical period in a water supply system for multiple uses (Cinara, 2006; Ospina 2009; Smits, 2010).

Household selection: As part of the household survey carried out within objective 1, respondents were asked whether they were willing to participate in a more extensive study related to household water usage. It was explained the information was used for academic purposes and confidentiality provided. 60 households from the 134 interviewed answered positively to this question. The list of customers that showed interest was discussed with the system caretaker to reduce the number of households to be approached. Households on the most distant villages, *El Agrado*, *Ventaquemada*, *Colegurre* and *Chontaduro* were not included, since there was few and very scattered households on those (15% of the population) and in contrast, *Tres Puertas*, *Buenvivir, Monteredondo* and *La Palma* concentrated the bulk of the population served by the water system (85%). From this meeting, the number of households was reduced to 22 as shown in Table 4-6.

Table 4-6 Potential households to conduct the water usage monitoring

Stratum	Population	Surveyed households	Interested surveyed households	Reduced list with the caretaker	Location			
					A	B	C	D
1	37	17	9	3	1	1	1	0
2	205	84	49	14	3	2	9	0
3	70	33	15	5	0	1	3	1
Total potential households by location					4	4	13	1

A: *Tres Puertas*. B: *Buenvivir*. C: *La Palma*. D: *Monteredondo*

From this refined list, it was decided to exclude from this activity households on *Monteredondo* and *Tres Puertas* and just to work with households on *Buenvivir* and *La Palma*. *Buenvivir* concentrated 21% of the population and *La Palma* 30%. 17 potential households on these two villages were approached to explain in detail what was the water usage monitoring about and asked if they were still interested to participate within the research, stressing again confidentiality issues and the purpose of the study.

Six households agreed to take part, although, the monitoring methodology had to be adjusted according to owners concerns and requirements. The initial proposed methodology was for the author to stay at the selected houses for one day from 6:00 a.m. to 6:00 p.m. taking data on the activities developed by the family, regarding the use of water. Although, when the first users were approached and this methodology was uncomfortable for them and the first two houses refuses, the author took the decision to propose two options to participate. The first one was to do it in the initial way and the second was for a household member who knows how to read and write to fill a water diary for one day. Most of the time, housewives received this information and took the decision to participate, since they were at home, while men were working at the fields. In this way, seven households agreed to participate on the study. Five housewives chose to fill the diaries and two chose allow the author to stay at the premises, although, one of them agreed to start the monitoring after 11:00 a.m. which was not really useful, therefore, this house was rejected. The participant houses were distributed one on the stratum 1, two on the stratum 2, and three on the stratum 3. All the people who decided to fill the diaries were young-adult housewives. In these households, appointments were set to explain to woman how to fill the diaries, train them on the measurement devices and to conduct flow and volume measurements for the water abstraction devices.

Women training and water abstraction devices measurements: Women were visited at their premises to deliver the diaries and explain how to fill them. The activity started with a semi-structured interview to review the household water uses, make an inventory of water abstraction devices for every water use, water storage units, meters, etc. Women were also asked about activities not developed every day. After that, the diary was explained. The diary consisted on three sections; one for the use of the toilet, one for bathing, hand washing and brush teeth, and the last one for the activities that occur in other areas of the house. The sections included five basic questions:

- What time was the water use? In this question respondents had to write hour and minute when activities related to water were carried out.
- What was the water use for? In this question respondents had to write the activities developed that involved the use of water. i.e. to prepare coffee, to wash body, etc.
- What was used to take the water? In this box respondents had to include the device used to extract the water. i.e. kitchen tap, white container, shower tap.
- What quantity of water was used? In this box respondents had to write the time during which tap was opened or the number of times they used a container to extract water for the activity developed
- Who use the water? this box had to be filled with the name of the household member who use the water for the activity
- Observations: Any comments respondents want to include.

The form for the toilet use was almost the same, but just included the time, if it was cleaned by a flush or with water poured with a container, the number of flushes or containers used, and observations.

It was detailed explained to woman and other family members how to fill the diary and a watch with chronometer was delivered in every household. Women were told that they could keep the watch after the monitoring, which was a good strategy to motivate them. It was emphasized and practiced how to record water quantities.

After remembering the household water uses and explaining the diary, an inspection was carried out to recognize the water points used for each activity and to take flow measurements on the water taps and volume measurement of the containers used for the activities. The flow was measured in all water household taps, asking people to open the taps in the degree they normally used. The volume of the containers people use to extract water, i.e. in the *lavadero*[6] was also measured. People actively participated in these measurements. Basically, four methods were adopted based on those reported by Roa & Brown (2009):

- Water flows from taps were collected with containers suitable to the space and volume delivered and the stopwatch. Then the collected volume was measured with a graduated cylinder of 500 ml.
- In the case where water was taken from storage tanks trough containers, the volumes of these were measured also with the graduated cylinder of 500 ml. Women were asked to fill the containers at the level they normally used and also during the monitoring to try to use the water at the same level.
- The volume discharged by flush toilets was measured with the tank´s geometry, taking into account their surface area and the drop level in the tank after the flush.
- For pour flush toilets, the volume of the container normally used for cleaning was also measured.

It was agreed with the housewives to fill the diary during the day following the explanation. In the household that chose that the author stay and observe the water use, the activity started at 6:00 a.m. and finished at 4:30 p.m. The author and a trained assistant recorded all the water related activities carried out by the family members and conducted flow and volume measurements at times where water was not in use. Family members listed the activities they usually conduct for the rest of the period and since those were the same than those developed previously during the day, estimations were done to complete the 24 hours period. Figure 4-2 shows one woman who filled the diary in one of the participant households next to her *lavadero*.

6 Place outside the home where people use to wash clothes by hand, and even for other purposes at the homestead, i.e. washing dishes, brush teeth, etc. In *La Palma – Tres Puertas lavadero*s are provided with relatively large tanks to store water.

Figure 4-2 Housewife in one of the monitored households

Data management: Data from each household and for categories of use was transferred after the monitoring day to individual record sheets and water consumption was calculated based on frequency, time, flow and volume measurements.

Data analysis: Data from the measurements was computed using Excel spreadsheets. The distribution of domestic water consumption which correspond to uses such teeth brushing, hand washing, cooking, bathing, washing dishes, washing clothes, sanitation, housekeeping and garden irrigation were obtained from this information. The total water daily domestic consumption and per capita domestic water consumption was also calculated. Averages of the six households for all these parameters were also computed.

As for Objective 1, results were discuss in terms of the literature review and the research questions, establishing principles, relations, generalizations, commenting on correlation faults and comparing this information to previous work developed by other authors in relation to these topics.

Limitations:

- As noted by Bramfit et al. (1997) the time limit of 1 day precluded the research from covering weekly variations in water usage, as well as seasonal variations
- Despite that, the initial purpose of this activity was to conduct measurements for both domestic and productive uses, since women agreed to fill the diaries; the collected information was restricted to domestic uses.
- As for the household survey, despite informed consent, most people did not feel comfortable with household observations, especially on issues related to water service, leading to a low participation

- In some households, people could reduce their normal water consumption since they could think they did not want to be seen as people who waste water.

4.3 Proposal of balances at the system and household level including water demand for multiple uses and water inputs, considering blue water and green water

Water accounting tools together with information from the meter records, household survey, household monitoring, climatic information and storage tank flow measurements were used to produce the water balances.

The water balance analysis covered households served by the water supply system (respondents to household survey) for the period of May and June 2010, as most of the information required for the balance was available for this period. According to historical data (Cenicafé, 2010) these months represents dry season conditions. An initial draft of the water balance was prepared based on the available information for the area (Cinara, 2006; Ospina, 2009), literature about water supply and multiple uses of water in Colombia, and literature about water balances, cited in this document (Perry, 1996; Molden, 1997; McKinney et al, 1999; Rosegrant et al., 2002; Ratnaweera et al., 2006; Healy et al., 2007). The sketch appears in Figure 4-3. The boundaries of the system were defined according to the research purposes and the information that was feasible to acquire for this region.

Based on the sketch the information needed to describe the balance was collected during the fieldwork period as described below:

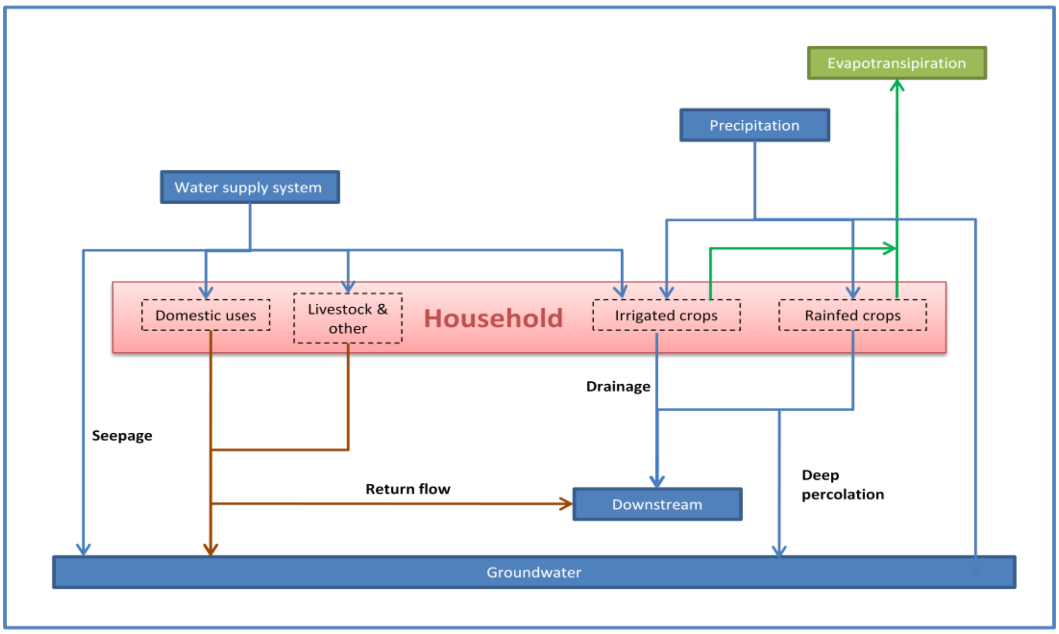


Figure 4-3 Initial proposed sketch for the water balance

Inflows: Inflows were represented for the total amount of water flowing into the domain from precipitation and surface and subsurface sources (Molden, 1997). It was already known that the use of subsurface sources through collective or private systems like boreholes, wells or springs was negligible, so as well the use of alternative small streams (Cinara, 2006). This information was verified during the fieldwork period, where people were interviewed about the different sources they use for different purposes, and the answers indicated that inflows were represented mainly for the water supply system and rainwater.

Findings from Cinara (2006) and Ospina (2009) highlighted that the water supply system was used for domestic uses, livestock, coffee processing, fumigation, and as supplemental source for crops. The studies indicated that rainfall was the main water source for crops and water harvesting was not practiced in the area. This information was also verified during the household survey being accurate. With this information, water supply and rainfall inputs were established through the next methods:

Water supply: The water entering to the centralized storage tank of the water supply system of *La Palma Tres Puertas* that collect water from the sources La *Tobón* and *Sinaí* was measured five times during July 2010. The water supply system caretaker was trained by the author to take these measures. Materials and forms were provided to him to conduct measurements and record results. Data was transferred to an Excel spreadsheet. Volume supplied was calculated as the average of the data taken, and it was considered representative for the analysis period.

Rainfall: Precipitation for the analysis period was obtained from records of *Julio Fernandez* Climate Station located within the study area and provided by Cenicafé. In this Station the variables measured are temperature, rainfall, number of hours of sunshine, solar radiation, relative humidity, and wind evaporation. Rainfall is measured by a rain gauge with records taken at 7:00, 13:00 and 19:00 every day. Figure 4-4 shows *Julio Fernandez* climatic station.

Figure 4-4 *Julio Fernandez* Climatic Station

Outflows: Outflows were divided in six major categories:

Domestic consumption: Comprises uses such as drinking, food preparation, bathing, sanitation, washing clothes, brushing teeth, hand washing and garden irrigation (ornamental plants). It was estimated from the household survey using the household size, understood as the number of people within a household and a factor for domestic per capita water consumption. This factor was informed by literature review and the household monitoring conducted for the Objective 2.

Livestock consumption: Comprises water consumption for the livestock that people kept at the household. From the household survey it was identified those animals were: chickens, pigs, cows, horses and in a minor scale rabbits and guinea pigs. The survey also provided the number of animals per species. The quantity of animals was multiplied for a water consumption factor selected according to the reference values provided by literature sources (Roa, 2005; Barrios, 2008; Ospina, 2009) and having into account the conditions of *La Palma Tres Puertas*, information from local people and observation. The factors included the required amount of water for drinking and cleaning purposes.

Coffee processing: It was estimated as suggested by Ospina (2009) taking into account the coffee productivity per hectare for the region, the specific water consumption per pound of produced coffee, according to different processing systems, and the cropped area of each household. The most common coffee production system in *La Palma Tres Puertas* is coffee with shadow, which productivity of 1398.5 kgPC/He*year (Ospina, 2009). In this region (3° - 4° North Latitude), the harvest occurs two times a year: the main runs from September to December and a lower harvest from April to June called “Traviesa”. “Traviesa” productivity is approximately 40% of the total annual productivity (Cenicafé, 2006). Thus coffee productivity was considered approximately the 25% of the total productivity (0,35 $KgPC/m^2$) in order to reduce the April production since this month was not part of the analysis period. On the other hand, three water consumption factors for coffee processing were considered according to the main processing systems (Ospina, 2009): Traditional 0,04 $m^3/KgPC$, Tank-Tube 0,0042 $m^3/KgPC$ and Belcosub 0,001 $m^3/KgPC$. The water consumption for coffee processing per each household was obtained by multiplying these factors for the area planted informed by the household survey.

Small Business: It was identified a small amount of stores (3). In these stores, usually people just run the business and in some cases, owners lived there and in some other cases they did not. In any of these cases crops, livestock or other water related uses were developed. Thus, the consumption in this category was estimated by subtracting the domestic water consumption if they had, to the total water consumption.

Crop consumption - irrigation: Crop type and cropped area per homestead for the analysis period were obtained from the household survey; crop water requirements were estimated according to the methodology suggested on the Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper vol. 56 (Allen et al., 1998). To apply this methodology the following information was obtained:

Climatic information:

- Crop reference evapotranspiration (ETo): Obtained using the CROPWAT software which uses the FAO Penman-Monteith method and which computes this parameter from climatic data such as Mean Maximum and Mean Minimum Temperature, Air Humidity, Wind Speed and Daily Sunshine for the period of analysis, available parameters at *Julio Fernandez* Station. Information related to the Altitude, Latitude and Longitude of the station is also required to use this software.
- Effective precipitation (Pe): was obtained through CROPWAT by providing Total rainfall in mm/month for the study area. This software computes effective precipitation using the Soil Conservation Service - SCS method. Precipitation was obtained from *Julio Fernandez* Station.

Crop information:

The total crop growing period was obtained from the Agronomic Guide for the representative crops of *Valle del Cauca* department (Gobernación del Valle del Cauca, n.d.). The total period was divided in initial, development, media and final stage by adapting the length of the stages proposed by Allen et al. (1998) to the total crop growing period for the local conditions. From this information crop calendars were prepared as suggested by Brouwer et al. (1992) having into account cropping patterns for the region informed by FAO (2006), and observations during the field work and informal interviews to local people. Crop coefficients (kc) were selected for each crop and development stage from the literature review (Allen et al., 1998; Ospina, 2009). Crop water use was calculated as suggested by Brouwer & Heibloem (1986) Equation 4-2:

$$ETc = ET_0 \times K_c$$

Equation 4 – 2

with

ETc = Total crop water need (mm/month)

Kc = crop factor

ETo = reference evapotranspiration (mm/month)

Crop water use from the rain (Crops green water consumption – CGWC) was equal to the minimum value between Etc and Pe (mm/day) and Crop water need from the water supply system (Crops blue water consumption – CBWC) was calculated using Equation 4-3:

$$CBWC = ETc - Pe \qquad \text{Equation 4-2}$$

Where:
ETC is Total crop water need (mm/month)
Pe is Effective precipitation given (mm/month)

Calculations were developed separately for May and June 2010, then added to account for the total crop water requirement of the analysis period, and converted to m/period.

Crop consumption - fumigation: It was estimated accounting for the insecticides, fungicides and herbicides dosage, number of applications in the period for each crop and cropped area. Ospina (2009) used this methodology and specifies the main parameters for conditions in *La Palma – Tres Puertas,* where crops are developed at small-scale and applications are made with a back pump (20 litres capacity). Some local farmers also informed about the quantity of water used to fumigate some of the crops and this information was used in the case of guava and *pitaya*. Table 4-7 shows the selected factors for this use.

These factors were multiplied by the cropped area for each crop informed by the household survey to obtain the crop requirement for fumigation.

Table 4-7 Factors used to estimate fumigation water demand

Crop	Dose (l/He*month)	Factor (m^3/m^2*period)
Vegetables	212[1]	0,000042
Beans	283[1]	0,000057
Pineapple	50[1]	0,000010
Guava	130[2]	0,000026
Pitaya	300[2]	0,000060
Maize	150[1]	0,000030
Cain	75[1]	0,000015
Lulo	90[1]	0,000018

[1] Ospina (2009) ; [2]Local farmers

Swimming pools consumption: Information from the household survey indicated the presence of swimming pools in three farms. The water consumption required for this purpose was obtained from the difference between total water consumption of the household and the remaining uses the household had.

Equations, factors and variables used to estimate water consumptions for the different purposes are summarized in Table 4-8.

Table 4-8 Equations, factors and variables to estimate water consumption for MUS

Water Use	Formula	Variable	Factor
Domestic consumption (DC)	$DC = Household\ size \times Domestic\ percapita\ \ consumption \times \frac{60}{1000}$	Household size	
		Domestic per capita consumption (lpcd)	75 l/capita*day
Livestock consumption (LC)	$LC = \left(\sum_{i=7} Number\ of\ animals\ especie_i * Water\ consumption\ factor\ especie_i\right. \times \frac{60}{1000}$	Number of cows	40 l/head*day
		Number of chickens	0,15 l/head*day
		Number of pigs	20 l/head*day
		Number of horses	20 l/head*day
		Number of rabbits	0,5l/head*day
		Number of guinea pigs	0,5 l/head*day
		Number of ducks	0,3 l/head*day
Coffee processing consumption (CPC)	$CP = Productivity\ factor \times Water\ consumption\ system\ factor \times Cropped\ area\ \times \frac{60}{1000}$	Water consumption system factor	0,04 00 m^3/KgPC
			0,0042 m^3/KgPC
			0,0010 m^3/KgPC
		Productivity factor	0,035 KgPC/m^2
		Cropped area (m^2)	
Small business consumption (SBC)	$SBC = Total\ household\ consumption - DC$	Total water consumption	
		Domestic consumption	
Crop green water consumption (CGWC)	$CGWC = \sum_{i=14} Area\ crop_i \times\ Green\ water\ consumption\ factor\ c$	Cropped area with coffee	0,1465 m/period
		Cropped area pineapple	0,0465 m/period
		Cropped area beans	0,0705 m/period
		Cropped area maize	0,1465 m/period
		Cropped area vegetables	0,1465 m/period
		Cropped area *pitaya*	0,0837 m/period
		Cropped area *lulo*	0,1465 m/period
		Cropped area plantain	0,1465 m/period
		Cropped area cassava	0,1465 m/period
		Cropped area citrus	0,1209 m/period

Water Use	Formula	Variable	Factor
		Cropped area sugar cane	0,1465 m/period
		Cropped area guava	0,1465 m/period
		Cropped area pasture	0,1116 m/period
		Cropped area sown pasture	0,1465 m/period
Crop blue water consumption (CBWC)	$CBWC = \sum_{i=14} Area\ cropi * Blue\ water\ consumption\ factori$	Cropped area with coffee	0,0209 m/period
		Cropped area pineapple	0 m/period
		Cropped area beans	0 m/period
		Cropped area maize	0,0132 m/period
		Cropped area vegetables	0,0209 m/period
		Cropped area *pitaya*	0 m/period
		Cropped area *lulo*	0,0395 m/period
		Cropped area plantain	0,0488 m/period
		Cropped area cassava	0,0488 m/period
		Cropped area citrus	0 m/period
		Cropped area sugar cane	0,0488 m/period
		Cropped area guava	0,0209 m/period
		Cropped area pasture	0 m/period
		Cropped area sown pasture	0,0302 m/period
Crop fumigation consumption (CFC)	$CFC = \sum_{i=14} Area\ crop_i * Fumigation\ factor\ cropi$	Cropped area pineapple	0,000010 m^3/m^2*period
		Cropped area beans	0,000057 m^3/m^2*period
		Cropped area maize	0,000030 m^3/m^2*period
		Cropped area vegetables	0,000042 m^3/m^2*period
		Cropped area *pitaya*	0,000060 m^3/m^2*period
		Cropped area *lulo*	0,000018 m^3/m^2*period
		Cropped area sugar cane	0,000015 m^3/m^2*period
		Cropped area guava	0,000026 m^3/m^2*period
Swimming pool consumption (SPC)	$SPC = Total\ Household\ consumption\ (TH - DC - LC - CPC - SBC - CBWC - CFC$	Total water consumption	
		Domestic consumption	
		Livestock consumption	
		Coffee processing consumption	
		Small business	

Water Use	Formula	Variable	Factor
		Consumption	
		Crop blue water consumption	
		Crop fumigation consumption	

Balance Adjustment: After defining the components, variables and factors for the water balance, a spreadsheet was prepared on Excel including all the information provided in Table 4-8. A formula for the water balance was included to check that for every household the total amount of water taken for the analysis period (meter record) was equal to the addition of the different estimated components described before. The Formula appears on Equation 4-3:

$$THC = DC + LC + CPC + SBC + CBWC + CFC + SPC \quad \text{Equation 4-3}$$

Where:
THC = Total Household Consumption provided for meters records
DC = Domestic Consumption
LC = Livestock Consumption
CPC = Coffee Processing Consumption
SBC = Small Business Consumption
CBWC = Crop Blue Water Consumption
CFC = Crop Fumigation Consumption

From Equation 4-4 the "validity" of the previous assumptions was tested. For instance, a consumption factor was initially included for domestic uses as 75 lpcd according to the results of the household water monitoring (Objective 2). This factor was checked with the water balance equation for the households that have exclusively domestic uses and it was decided to make it variable to be able to balance the equation. The same process was performed to check the factors for animal species, coffee processing and fumigation. After that, crop water requirements to the water supply system were included. By doing this, all the balances were negative in big proportions for the households with crops, which require irrigation. Thus, it was decided to check individually the survey to find in people answers if they irrigate the crops and it was found that most responses to this question were negative for most of the crops, in most of the cases, except for some households who grow vegetables, maize, guava and *lulo*. Few people (11) which grow plantain, cassava and sugar cane, despite having "no" answers about irrigation had surplus that cannot be associated to other uses, and since these crops require irrigation, the surplus was assigned to this category of consumption. Therefore, it was decided to take the crop water requirement as the surplus obtained from subtracting the domestic consumption, coffee processing and livestock consumption to the total household water consumption. It was carried out just for households that have crops, which require supplemental irrigation, according to the previously calculated needs with FAO methodologies (Allen et al., 1998; Brouwer et al., 1992).

Adjustments were done checking the information from each household in order to make the addition of the estimated consumptions equal to the total water consumption indicated by the meter records. After this process, "validated" equation, variables and factors were obtained and appear in Table 4-9.

Table 4-9 "Validated" equation, factors and variables to estimate water consumption for MUS

Water Use	Formula	Variable	Factor
Domestic consumption (DC)	$DC = Household\ size \times Domestic\ percapita\ \ consumption \times \frac{60}{1000}$	Household size	
		Domestic per capita consumption (lpcd)	
Livestock consumption (LC)	$LC = \left(\sum_{i=7} Number\ of\ animals\ especie_i * Water\ consumption\ factor\ especie_i \times \frac{60}{1000}$	Number of cows	40 l/head*day
		Number of chickens	0,15 l/head*day
		Number of pigs	20 l/head*day
		Number of horses	20 l/head*day
		Number of rabbits	0,5l/head*day
		Number of guinea pigs	0,5 l/head*day
		Number of ducks	0,3 l/head*day
Coffee processing consumption (CPC)	$CP = Productivity\ factor \times Water\ consumption\ system\ factor \times Cropped\ area\ \times \frac{60}{1000}$	Water consumption system factor	0,0042 m^3/KgPC
		Productivity factor	0,035 KgPC/m^2
		Cropped area (m^2)	
Small business consumption (SBC)	$SBC = THC - DC$	Total water consumption	
		Domestic consumption	
Crop green water consumption (CGWC)	$CGWC = \sum_{i=14} Area\ crop_i \times\ Green\ water\ consumption\ factor\ c$	Cropped area with coffee	0,1465 m/period
		Cropped area pineapple	0,0465 m/period
		Cropped area beans	0,0705 m/period
		Cropped area maize	0,1465 m/period
		Cropped area vegetables	0,1465 m/period
		Cropped area *pitaya*	0,0837 m/period

Water Use	Formula	Variable	Factor
		Cropped area *lulo*	0,1465 m/period
		Cropped area plantain	0,1465 m/period
		Cropped area cassava	0,1465 m/period
		Cropped area citrus	0,1209 m/period
		Cropped area sugar cane	0,1465 m/period
		Cropped area guava	0,1465 m/period
		Cropped area pasture	0,1116 m/period
		Cropped area sown pasture	0,1465 m/period
Crop fumigation consumption (CFC)	$CFC = \sum_{i=14} Area\ crop_i * Fumigation\ factor\ cropi$	Cropped area pineapple	0,000010 m^3/m^2*period
		Cropped area beans	0,000057 m^3/m^2*period
		Cropped area maize	0,000030 m^3/m^2*period
		Cropped area vegetables	0,000042 m^3/m^2*period
		Cropped area *pitaya*	0,000060 m^3/m^2*period
		Cropped area *lulo*	0,000018 m^3/m^2*period
		Cropped area sugar cane	0,000015 m^3/m^2*period
		Cropped area guava	0,000026 m^3/m^2*period
Crop blue water consumption (CBWC)	$CBWC = THC - DC - LC - SBC - SPC - CFC$	Cropped area maize	
		Cropped area vegetables	
		Cropped area *lulo*	
		Cropped area plantain	
		Cropped area cassava	
		Cropped area sugar cane	
		Cropped area guava	
Swimming pool consumption (SPC)	$SPC = DC - LC - CPC - SBC - CBWC - CFC$	Total water consumption	
		Domestic consumption	
		Livestock consumption	
		Coffee processing consumption	
		Small business Consumption	
		Crop blue water consumption	
		Crop fumigation consumption	

Cleaning of the database: households whose water use and estimated demands showed significant differences (positive or negative) in the total water consumption indicated by the meter records were removed from the database. Therefore, from the initial list of 134 households a more reliable database with 106 registers was obtained.

Other water balance components estimation:

Return flows: return flows comprises the uses of water at farm level that become wastewater, such as water used for sanitation, shower, hand washing, clothes washing and brushing teeth. The use of water for washing pig sheds and processing of coffee was also considered. This flow of water was calculated using Equation 4-4:

$$Return\ flows = 0{,}8DC + 0{,}6LC_{pigs} + CPC$$

Equation 4-4

Where:

DC = Domestic Consumption (m^3)

LCPigs = Pigs Consumption (m^3)

CPC = Coffee Processing Consumption (m^3)

0,80 factor which account for the proportion of the total water used for domestic purposes which become wastewater, informed by results from household water use monitoring (Objective 2)

0,6 factor which account for the proportion of the total water used for pigs which become wastewater, informed by (Roa, 2005; Barrios, 2008) and some field observations

In this system, however, since there is no collective wastewater collection and transport system and these flows are handled at site, most of this water flow eventually infiltrates into the ground.

Runoff (R): Excess flow from rain that flows over the land

$$R = \frac{P_T - P_E}{1000} * Area$$

Equation 4-5

Where:

PT = Total rainfall for the period (mm)

P_E = Effective precipitation for the period (mm)

Area = total area of the homesteads in m^2 provided by the household survey

Downstream + Groundwater (DW + GW): Considered as the amount of water that falls from rainfall, is not harvested or used by crops. It was estimated by Equation 4-6:

$$DW + GW = P_T - R - CGWC$$

Equation 4-6

Where:

P_T = Total rainfall for the period (m^3)

R = Runoff (m^3)

CWGC = Crop Green Water Consumption (m^3)

The information below was calculated as well:

Per household:

- Total daily per capita consumption
- Domestic daily per capita consumption
- Productive daily per capita consumption (total and according to categories of productive use)

Per stratum:

- Average total daily per capita consumption
- Average domestic daily per capita consumption
- Average daily productive per capita consumption (total and according to categories of productive use)
- Average daily per capita green water used by crops
- Average daily per capita return flows
- Average daily per capita downstream and groundwater flows

At system level

- Volume of domestic water consumed per period[7]
- Volume of productive water consumed (total and according to categories of productive use)
- Volume of green water used by crops
- Volume of return flows
- Volume of downstream and groundwater flows
- Distribution of the water supply inflow according to categories of use, and according to stratum
- Distribution of the rainfall inflow according to categories of use

[7] The period refers to the two months on May and June 2010, that represents dry season conditions

Results were discussed regarding concepts presented on the literature review and to the light of the research questions formulated.

Limitations:

- The water balance developed was indicative, based on rough information and several assumptions
- A big proportion of the meters in this system were broken, some of them have been in this condition for more than three years, and therefore it was not possible to include these households within this study
- The effect of the household storage tanks was not included on the analysis performed, which may have an impact, specially in the case of few (2) households which storage capacities about 100 m^3
- Livestock consumption factors represent a significant uncertainty since aspects such as age or status of animals (significant for cattle and pigs) and type of cattle (i.e. Dairy or Beef cattle) which are important for water demand estimations were not included on the household survey
- Coffee processing consumption estimations can be inaccurate since annual coffee productivity for the region varies significantly in the different literature sources. It would be better to ask on the household survey the coffee processing system to avoid make this assumption and in contrary, to have data on this aspect
- Regarding to crop water requirements information of crop coefficients for some of the species grown on the area are not reported in the available literature
- Areas of the homesteads provided by people may be not accurate
- Some of those interviewed could report a smaller amount of assets (area planted, number of livestock) of interest to the water consumption estimations for fear to be charge by taxes, etc.

5 RESULTS AND DISCUSSION

This chapter presents and discuss the findings from the research activities carried out, in relation to the literature review and the research questions posed. Section 5.1 presents and discuss findings, making relations between categories of households based on water consumption (strata), and poverty, productive activities, livelihoods and access to water; Section 5.2 presents and discuss results related to water consumption for domestic purposes, according to different categories of domestic use, obtained from the household monitoring in six participant households. Section 5.3 includes results and discussion on water consumption for productive activities; water availability, and interaction between blue and green water to supply demands, developed using the water balance approach. Most results are presented and discussed in terms of the strata defined on the methods chapter.

5.1 Characteristics of households within a MUS system, according to poverty, livelihoods and access to water

This section presents and discusses the results of the activities undertaken to address Objective 1: To characterize groups of households within a MUS system, according to aspects related to poverty, productive activities, livelihoods and access to water.

5.1.1 Poverty and water consumption

From the literature reviewed on poverty and sustainable livelihoods (Haughton & Khandker, 2009; UNDP, 2003; UNDP, 2006; UNDP, 2007; World Bank, 2009; Ashley & Carney, 1999 and Nicol, 2000) it was possible to identify some aspects or indicators that help to describe when people are poor or are more likely to be. Some of these aspects considered for this project were: location, amount of land that is available, property of the land, the number of people living in a house (household size), the occupation of the household head, and finally, the monthly income a family can acquire from the activities carried out for their survival. These indicators were related to water consumption.

As expressed in section 1.6 Scope, in this research, a household is considered as the building where people have shelter and its surrounding areas, in most cases owned by the family, in which people may develop income-generating activities.

Figure 5-1 presents household area in relation to water consumption. 39% of the people which had water consumption less than 20 m^3/every two months (stratum 1) had households with areas less than 500 m^2, while in strata 2 (20 – 80 m^3/every two months) and 3 (> 80 m^3/every two months) this proportion was just 8% and 4% respectively. People with household areas higher than 10 Hectare (100000 m^2) did not have a low water consumption (< 20 m^3/every two months). Most of the people served by this system were smallholders, with household areas less than 5 Hectares.

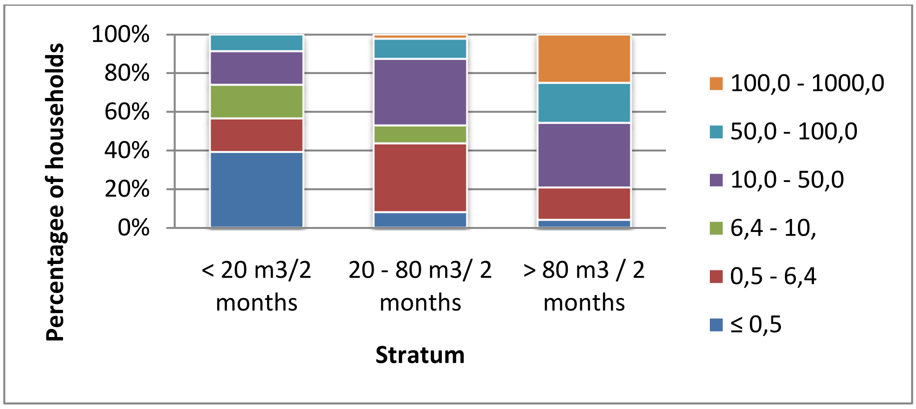


Figure 5-1 Household area (10^3 m^2) and water consumption

Figure 5-1 presents a significant relation between household area and water consumption. The Figure shows how people with less area used less water and the opposite. In the case of rural areas and multiple uses of water services, this may be related to the possibilities that people with more land available have to develop productive activities that depend on water to ensure their livelihoods. However, Figure shows the presence of users with high consumption of water and few available land. These cases were from people with productive activities that depended on water, but did not require large areas (i.e. raising one or two pigs); or people who grew crops that were less water demanding compared to other crops in the region. The graph also shows large-area households with low water consumption. This is due to two main reasons, large household areas where land was not productive or when the household size was 2 or less people.

Figure 5-2 presents the relation between household tenure and water consumption. It shows that users in all ranges of consumption were primarily homeowners, over 70% users in every stratum. In less than 10% in strata 1 and 2, houses were borrowed, and shared houses accounted for 5% in strata 2 and 17% on stratum 3.

The 70% of people in all strata who were homeowners, may have the ability to decide on the use of its assets, such as land and water, which may not occur in households in the category of borrowed and rented in stratum 1, where none of them (4/4) developed productive activities. There was a special case in 48% of the households which appear as own in stratum 3. These households belonged to people who did not live at those, and there was a proprietor’s house and another house for caretakers and their families. Caretakers lived permanently on the site, but the homeowners, for example, were only there for the weekend. In all these households a variety of productive activities was developed.

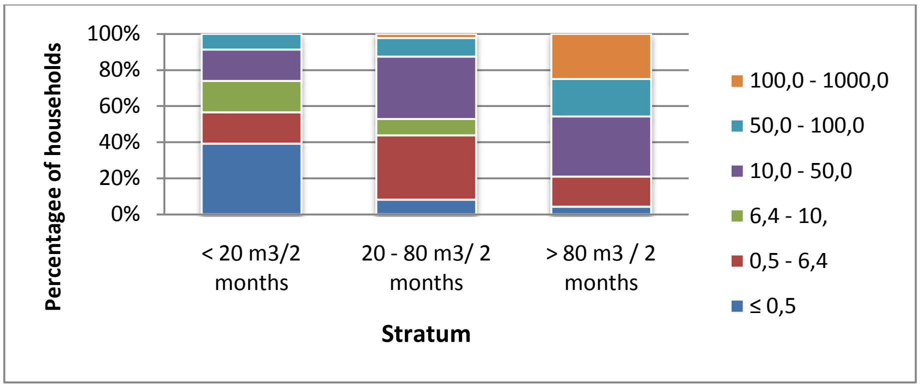


Figure 5-2 Household tenure and water consumption

Figure 5-3 presents the relation between household size and water consumption. 74% of households in stratum 1 were less than three members. Most families in stratum 2 and 3 were comprised of between 4 and 6 members. At all strata, less than 10% of families had more than 7 members.

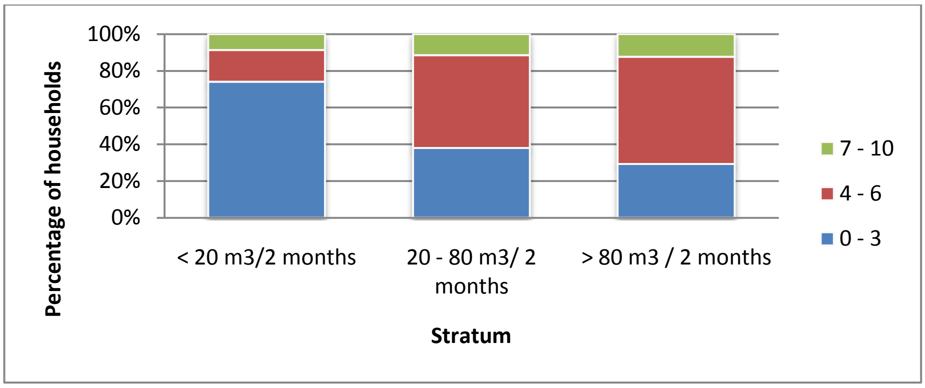


Figure 5-3 Household size and water consumption

The graph shows a relation between household size and water consumption, where households in stratum 1 had a significant proportion of less than three members and in strata with higher water consumption, the proportion of larger household size increases. Household size appears in some of the literature reviewed as a determinant variable for water consumption (Keshavarzi, 2006; Bramfit et al., 1997). Although, in this case, as productive activities are involved, this variable may influence mainly household consumption on strata 1 and 2, where, productive uses that depends on water are negligible (stratum 1) or moderate (stratum 2), but for stratum 3, where productive uses may have a bigger weight on water consumption, household size may not be a determinant variable.

The relation between household head occupation and water consumption is shown in Figure 5-4. There were significant proportions of farmers in stratum 2 and 3 (53% and 63%) compared to 13% of farmers in Stratum 1. The opposite occurs with day-labourers which proportion decreased when water consumption increased. Those were 30% for household heads in stratum 1 and 8% for household heads in stratum 3. Something similar applies to the unemployed, who were 35% of users in stratum 1 compared with 7% in stratum 2 and 13% in stratum 3.

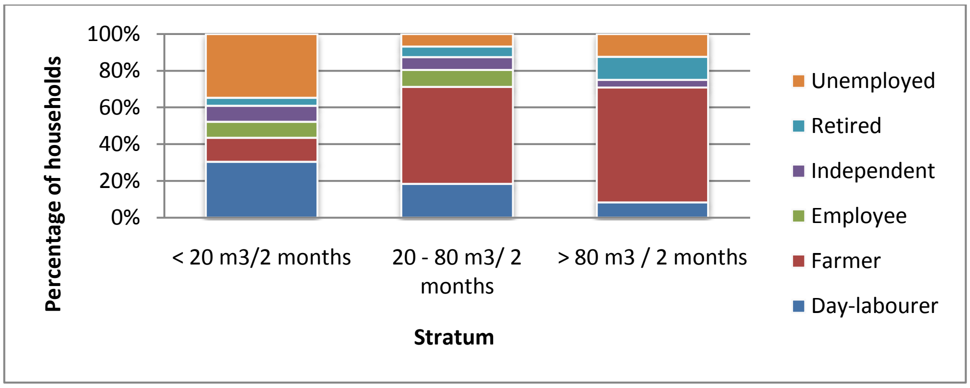


Figure 5-4 Household head occupation and water consumption

The relation between livelihoods and water consumption is clear from Figure 5-4. Livelihoods of people who work on strata 1 do not depend directly on the water they consume at their households. In this stratum, 52% of the household heads were day-labourer, independent, employees or retired. The proportion of unemployed people in stratum 1 was significant, 35%, although, 75% from this 35% had small quantities of pigs, or small areas with crops. The same happens in strata 2 and 3 with those that appear as unemployed, but the amount of animals or cropped land they had was bigger. This may be evidence of the importance of water for productive activities, to reduce vulnerability to external shocks (Moriarty & Butterworth, 2003), such as unemployment, which is significant in rural areas in Colombia.

Farmers were important proportions in strata 2 and 3, 53% and 63% respectively. It means that for these people, income generating activities depended on water. In the case of stratum 3, for those households where homeowners hired caretakers and did not live there, probably income did not depend solely on agricultural activities, but also on other activities in their places of permanent housing. However, in these cases, as in all homesteads agricultural activities were carried out, at least for the caretakers, all their income depended on access to water at the household.

Figure 5-5 describes the relation between income and water consumption. It indicates that around 20% of people in stratum 1 and 2 earned less than half the minimum wage in

Colombia (141 US$[8]) and there were no people on stratum 3 earning at this low level of income. In the three strata, between 45% and 59% earned between half and the country's minimum wage (141 - 278 US$) and this was the lowest income level for those in stratum 3. The largest percentage of people with higher income levels (more than 586 US$) were in stratum 3 (18%) compared with only 5% and 2% reported for stratum 1 and 2 respectively.

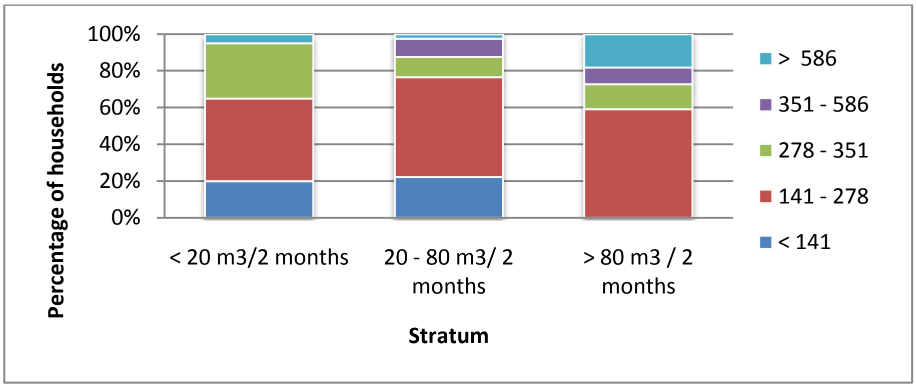


Figure 5-5 Household monthly income (US$) and water consumption

Taking into account the household size of both strata, those who earned less than 141 US$ per month lived with less than 2 US$/ day. Therefore, they would be the poorest people served by the water supply system. Although, looking at the behaviour of other variables for these people, in stratum 2, 78% of the 21% who earned less than 2 US$/day were day-labourers or farmers, and all of them did some kind of productive activity at their homesteads. This indicates that these activities were not enough to generate the revenue necessary for a better quality of life, situation very common in rural areas in Colombia (Pérez & Pérez, 2002). However, within these group of people, there were 4 cases where the household size was 2 (income per capita raises), and also there were 2 cases where incomes were lower than reported expenses, or where people had 10 cows, or more than 5 hectares. It shows that it is not easy to get accurate information related to people´s income and, the need to get this data through various methods (triangulation), especially, when interventions are looking to target the poorest of the poor.

In this way, it seems that the poorest in *La Palma Tres Puertas* were the 20% who earned less than 2 US$/day in stratum 1, did not have animals or crops, and were day-labourers, which means they did not work every day to get a better income level, and did not have other income sources.

[8] 1 US$ = 1850 COL$ (July 2010)

5.1.2 Livelihoods, productive activities and water consumption

As indicated by World Bank (2009) most poor people living in rural areas of developing countries, depend on agricultural production for their income. In *La Palma Tres Puertas*, as presented in the previous section, there were a large proportion of farmers, who cultivated their own land or day-labourers, who worked in agricultural activities, but on other´s plots. The results below show the scale at which these agricultural activities, specially cropping and/or animal husbandry were carried out in the region and how it relates to water consumption on the strata defined.

Animal husbandry: Most animals been raised were pigs, cows and poultry. Figure 5-6 summarizes the scale of animal husbandry. Stratum 3 had a much higher presence of pigs and cows in comparison to stratum 2 and 1. In all strata, pigs were raising in quantities from 1 to 5 (13%, 11% and 17% respectively). In the case of stratum 1, this 13% represented no more than two pigs. In Stratum 3 there were dwellings (4%) where this activity was developed on a large scale (150 pigs). 50% of users in stratum 3 had cows in quantities ranging from 1 to 100 units, with 13% on the upper limit; while all households on the stratum 2 had less than 50 cows. Poultry were in all strata; in strata 1 in 26% of the houses, and those accounted for 62% in both, strata 2 and 3. In more than 50% of households, families had less than 20 units. In stratum 2, there were some cases (1%) where this activity was developed at large scale (4000 units).

Raising animals was a widespread activity in the area at all levels and in all levels of water consumption. However, cows had a greater presence in the stratum of highest water consumption, even in large quantities, indicating that these animals may have a significant impact on household water consumption, as can be inferred from the values reported by the literature, regarding water consumption for these species (Nozaic, 2002; HR Wallingford, 2003; Ospina, 2009; Roa, 2005; Peden, 2007; Barrios, 2008). Pigs were raised at all levels, usually in small quantities and rarely on a large scale, being more an asset for emergency or sporadic income (Peden et al, 2007). Compared to the water consumption of cows, pigs consumption is lower (Nozaic, 2002; HR Wallingford, 2003; Ospina, 2009; Roa, 2005; Barrios, 2008), but quantities larger than 6 units may represent a significant proportion of the water household consumption. Thus, those who keep more than 6 pigs were located in stratum 3. In the case of poultry, they were intended for household food security rather than for sale when quantities were up to 20 units. Additionally, the impact of this species in water consumption is not significant, since 100 heads require about 20 l/day (Nozaic, 2002; HR Wallingford, 2003; Ospina, 2009; Roa, 2005).

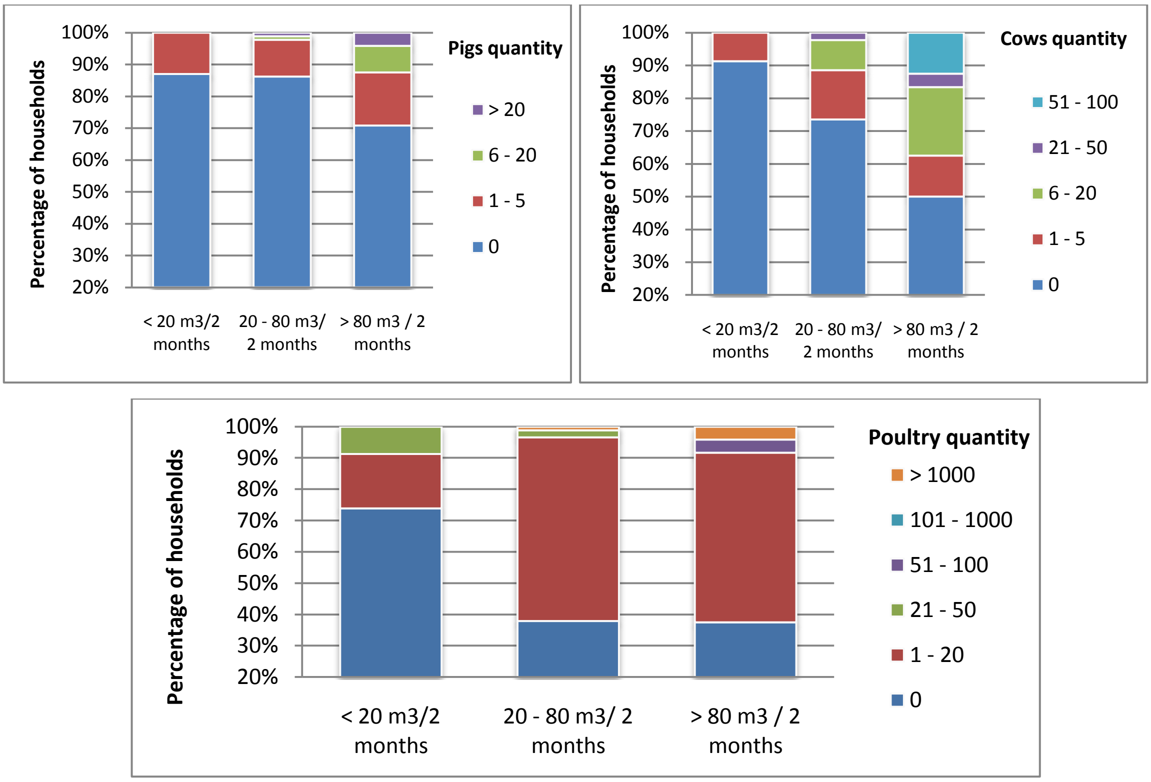


Figure 5-6 Animal husbandry and water consumption

Growing crops: Main crops in the area were coffee, pineapple, maize and beans. Some crops like *pitaya*, *lulo* and guava have being implemented in recent years.

Figure 5-7 shows cropped areas according to water consumption strata. In stratum 1, there was no presence of commercial crops like pineapples, *pitaya* and *lulo*, only a small proportion of coffee (4%). In stratum 2 people grew coffee in areas ranging from 3200 m^2 to 50000 m^2 and this activity was developed in 30% of homesteads. To a lesser extent, pineapple was grown in this stratum (8%), maize (17%), lulo, and *pitaya* (5% each). The users in stratum 3 planted less coffee (17%), but in larger areas (from 6400 m^2 to 50000 m^2). Pineapple was primarily grown in stratum 3 (34%). Maize was planted in most of the strata, but in small areas (less than 6400 m^2). A widespread practice was grow beans and maize together, although some maize was planted alone (4%) for sale in slightly bigger areas (10000 m^2) of stratum 3.

The presence of coffee in many of the farms in stratum 2 (30%) was due to most cropped areas were small (less than 10,000 m^2), coffee water requirements under the production system implemented in the area (shaded coffee) were supplied entirely by rainfall, limiting the need for water to the processing of the grain at harvest time. Therefore, it could be said, this is a water efficient crop. Also in this stratum 50% of the 30% coffee growers were dedicated exclusively to this activity.

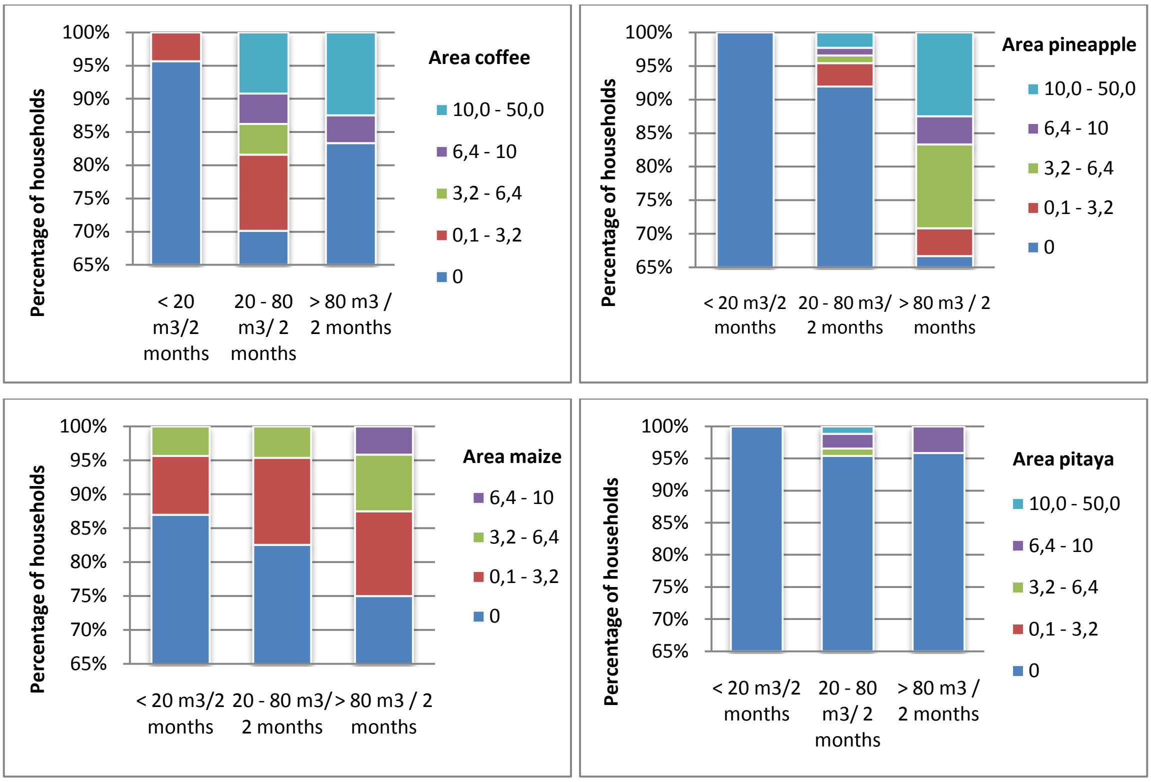


Figure 5-7 Areas planted (10^3 m^2) with major crops and water consumption

Most of the households who cultivated pineapple were in stratum 3. This crop does not need supplemental irrigation under the climatic conditions in *La Palma Tres Puertas*. Therefore, the presence of a greater number of pineapple and coffee growers in this stratum, may be explained by the fact, that these users developed a range of productive activities that depend on water simultaneously.

Maize was grown in all strata, but more for self-consumption, rather than as a cash crop, although in stratum 3 plots with maize were planted in relatively large areas compared to the "normal" size of cropped land in the region. The water needs of this crop are slightly higher than those for pineapple and coffee (Allen et al., 1998), and require supplemental irrigation. However, 55% of farmers in the area claimed not to irrigate this crop.

On the other hand, *pitaya* was also planted in relatively large areas of households belonging to strata 2 and 3. This crop is also efficient in water use (Ospina, 2009). It is also a very profitable crop. *Pitaya* and pineapple harvests occur after 24 months and 18 months of planting (Departamento de Agricultura del Valle del Cauca, n.d.), therefore, these are not crops poor people can have as their livelihood. Besides, in this region, these crops are produced using large quantities of agro-chemicals for which a substantial investment is required before obtaining any yield.

5.1.3 Access to water and water consumption

All categories of users in *La Palma Tres Puertas* defined in this document, according to water consumption levels (strata), had connections to the water supply system. However, since this service is intermittent, opportunities of access to water were mediated by different aspects, such as the household location in relation to the distribution network, the storage capacity of water at homes, and the frequency of service delivery. These aspects were included in this research, as it is recognized that poor people are more likely to receive lower quality services than the rich. This condition affects poor´s ability to develop productive activities that depend on water, and contribute to improving their quality of life (Yang et al., 2006; Hansen & Bhatia, 2004; World Bank, 2009; UNDP, 2006).

Figure 5-8 shows how users of different consumption categories (strata) were distributed in the service area. Households in stratum 1 were mainly in the settlements of *Tres Puertas* (26%), *Monteredondo* (26%), and *La Palma* (30%). Households in stratum 2 were in all settlements, mainly in *Buenvivir* (23%) and *La Palma* (33%). Users with high water consumption (stratum 3), were also spread over all the settlements, mostly in *La Palma* and *Tres Puertas* (25% each), but most households in *El Agrado* and *Ventaquemada* belonged to this stratum (50%) and (40%), while this area did not have households in stratum 1.

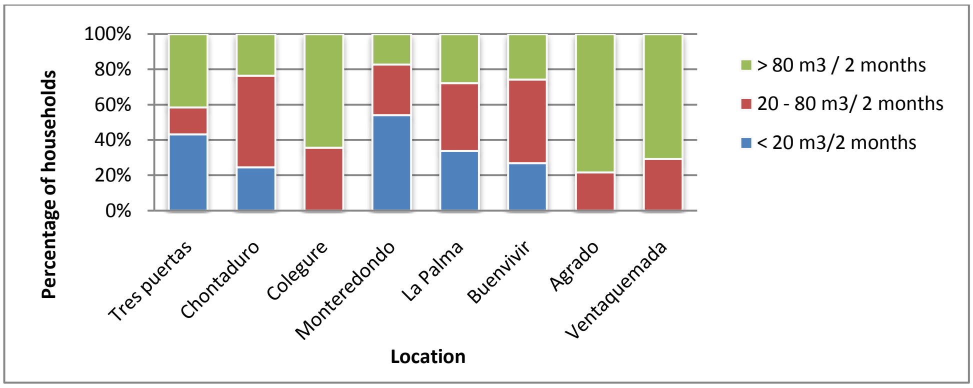


Figure 5-8 Location and water consumption

The villages of *La Palma* and *Buenvivir* had areas that concentrated several houses and therefore, some households in some of them were small, which restricts the possibilities for productive activities. For *Ventaquemada* and *El Agrado* households were more scattered and with larger areas, facilitating activities such as farming or ranching. For *Monterendondo*, where several people in stratum 1 lived, some respondents stated that the water was provided there less often; and in extreme dry season, some had to travel to a nearby source for bathing and washing clothes, and even one household was uninhabited, apparently for lack of water. One explanation to this situation is that the service comes to this area through a long branch, and maybe for technical factors such as losses, or low pressure, conditions for accessing water are more difficult there. Unfortunately, technical information like ground levels or pipe lengths was not collected to make a more accurate statement on this point.

Figure 5-9 presents the frequency of service provision in dry season to households in different strata. A higher proportion of users in stratum 1 (42%) and in stratum 2 (35%) received the service 1-4 times a month during dry season, while only (11%) had this level of service in stratum 3. The same happens in the opposite situation, where 36% of users received water in dry season from 9 to 16 times a month in stratum 3 and only 11% had this frequency in stratum 1. Few users in stratum 3 (7%) were served daily.

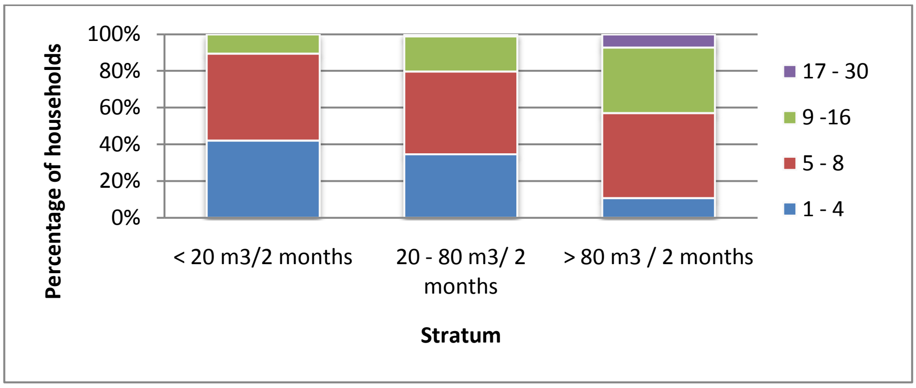


Figure 5-9 Frequency of service provision during dry season and water consumption

From Figure 5-9 is evident that households that use more water were served more frequently during dry season compared to households that used less water. However, in most cases the service was received 8 times per month. Some households that received the service more than 9 times per month were in areas surrounding the storage tank. This is a possible explanation for their better service level. Other issue may be the schedule of the shifts, which is according to branches. Households in branches with few customers (*Ventaquemada* and *El Agrado*) can also receive the service in better conditions compared to those located in more populated villages.

People had storage tanks at their premises. Figure 5-10 includes the relation between storage capacity and water consumption. 91% of households in stratum 1, 68% in stratum 2 and 59% in stratum 3 had storage tanks up to 5 m^3. There were no dwellings in stratum 1 with storage capacities greater than 10 m^3, while storages capacities greater than 10 m^3 were installed in 16% of households on stratum 2 and 21% in stratum 3. There was even a house in stratum 3, which had a 100 m^3 storage tank.

There is a direct relationship between storage capacity at the household level and water consumption. People who used more water had bigger storage tanks (Cinara, 2006). People whose income depends more on water, due to the intermittent nature of the service, adapted to these conditions to avoid losing their livelihoods, by building big storage tanks. For example, many tanks over 10 m^3 were in households where animal husbandry was developed at large scale; i.e. some had more than 10 cows, 4000 chicken, more than 100 pigs. In the case of people with storage tanks with lower capacity, such as up to 1 m^3, the maximum amount of cows reported was 5 units.

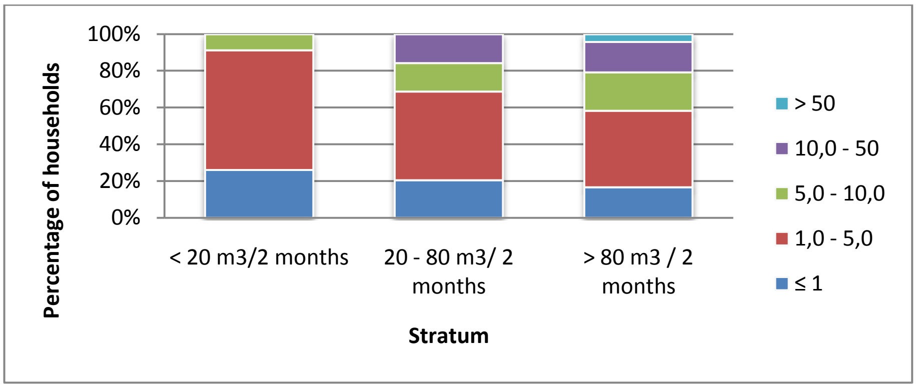


Figure 5-10 Storage capacity (m^3) and water consumption

Several women said they had to be alert to the time when the water arrived and wash clothes at night while the water was supplied. The service was usually delivered during the night and apparently, people did not know the day of provision. This situation occurs where storage tanks were small. In homesteads with larger storage tanks, there were comments on the fact that woman did not even perceive the service intermittence, since they always had water available in their homes for all their needs.

Figure 5-11 presents people´s perception on how affected they felt about the service intermittence. Those who felt more affected were users in stratum 2. 44% in this stratum answered they felt highly affected, while in stratum 1 the proportion of people who felt highly affected was 33% and 29% in stratum 3.

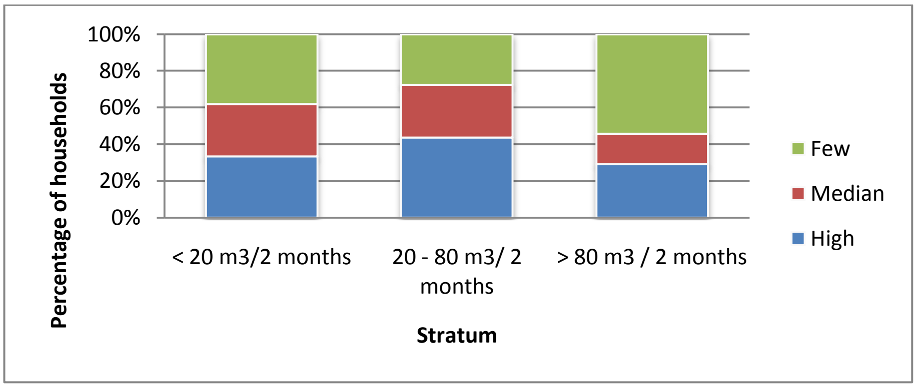


Figure 5-11 Perception about the impact of water intermittence

An explanation of the results from Figure 5-11 can be that, as most households in stratum 1 did not require water for their livelihoods in the same proportion that households in stratum 2, their tanks were sufficient and therefore, they did not feel highly affected by the lack of continuity in the service. Households in stratum 3, who used large amounts of water for their income generating activities, had mostly large storage tanks that allowed them to have the water they needed, despite of service intermittence. However, households in stratum 2, whose small-scale livelihoods depended on water as well, but had less storage capacity, perceived that lack of continuity had a greater impact over their domestic and productive needs.

One limitation of these results is that no information was elicited to identify whether the price paid for water (tariff) is a constraint to access, especially in the case of households with lower income levels and lower water consumption (i.e. households in stratum 1).

In Summary,
Households in stratum 1 were people whose income in most cases did not depend on having water at their premises, they were mostly day-labourers and unemployed, their farms were small, they did not have crops or animals and if they did, they had few. 20% of them lived on less than 2 US $/day. The majority had their own homestead, although, there were some that lived in borrowed and rented houses, which may limited their ability to use those households productively. They received the water service with lower frequency and their storage capacity at the household level was lower as well. A few proportion of them felt highly affected by water intermittence.

Households in stratum 2 were farmers, whose livelihoods depended mainly on a single productive activity developed on a scale that under this context, could be categorized as medium scale. Crops they grew were usually rainfed. Their income levels varied, as the size of their households and the productive activities they developed. In this stratum, although, there were farmers with little land and few assets, there were others with more land and more assets. The difference was that those with more assets adapted their water needs to the conditions of the area and had crops, which are water use efficient such as coffee, pineapple, pitaya, and other crops that can meet their needs with the rain. Animal husbandry was developed at small scale and was usually not the main productive activity from which income is derived. The storage tanks they had were in most cases between 1 to 5 m^3, although, few of them had tanks up to 50 m^3. A significant proportion of people in this stratum felt highly affected by water intermittence.

Households in the stratum 3 were farmers, although several did not live in *La Palma Tres Puertas* and thus, their income probably, did not depend solely on agriculture. These users were involved on animal husbandry, especially raised cattle on a larger scale, compared to the households in other strata. They also grew cash crops such as pineapple. Their farms had larger areas, and diverse productive activities that depend on water were developed simultaneously. Many of them had large storage tanks, higher frequency of water delivery and were located in areas where households were scattered or close to the storage tank. Their income levels were in all cases equal or greater to the current legal monthly minimum wage in Colombia (278 US$/month).

5.2 Domestic water per capita consumption in households within a MUS system

This section presents and discusses the results of the activities undertaken to address Objective 2: To measure different components of the domestic water per capita consumption in households within a MUS system.

As has been previously discussed, in most rural households water supply systems are used for domestic and productive activities (van Koppen et al., 2009; Moriarty et al., 2004). In general, international and national norms and guidelines used for planning purposes on the water sector, take into account quantities required specially for domestic uses, typically in a range of 25-40 lpcd (van Koppen, et al., 2006). In opposition to this approach, MUS promoters suggest that a water provision about 50-200 lpcd (Butterworth et al., 2003) is enough to develop domestic and productive activities at the household level and look for the consideration of the small-scale productive uses of water in conjunction with domestic uses from the planning stage of rural water supply systems.

This section presents the results and discussion of the efforts in this research to estimate the amount of water in *La Palma Tres Puertas*, used specifically for domestic purposes. The results shown are from the household monitoring developed in six households of the area, explained on section 4.2 on the methods chapter.

The six monitored houses used the water supply system as the only source for all domestic purposes. Table 5-1 shows some characteristics of the households related to aspects that may affect the water consumption for domestic purposes.

Table 5-1 Household characteristics affecting domestic consumption

Household ID	Household size	Children	Adult	Sanitation system	Frequency of service delivery		Storage capacity (m^3)	Household taps
					Days/week	Hr/day		
1	4	2	2	PFL	3	12	1000	3
2	4	2	2	PFL	2	8	2000	1
3	3	2	1	PFL	3	12	6000	4

Household ID	Household size	Children	Adult	Sanitation system	Frequency of service delivery		Storage capacity (m^3)	Household taps
					Days/week	Hr/day		
4	5	2	3	FT + ST	3	12	50000	6
5	4	0	4	FT + ST	2	12	5000	4
6	4	2	2	FT + ST	1	16	2000	6

PFL: Pour Flush Latrine; FT + ST: Flush Toilet + Septic tank

In most cases, number of people living in these households was 4. In all houses but household 5, there were two children. Those children were from different ages since months of birth up to 12 years. Regarding sanitation systems, 3 houses had Pour Flush Latrines and 3 houses Flush Toilets followed by Septic Tanks. As the service in the area is intermittent, the number of days a week different houses receive the service varies from 1 to 3, being 2 days the most frequent value. Families adapted to this situation having storage tanks with capacities from 1000 m^3 to 50000 m^3. The number of taps used for domestic purposes was variable, from one single tap for all uses located in the *lavadero,* up to six taps.

Domestic water uses: The domestic uses reported and the categories identified were grouped as appear in Table 5-2. The compiled information of the measurements from each of the six households appears in Appendix B.

Table 5-2 Categories of domestic uses measured and number of data

Category	Number of data	Category	Number of data
Cooking	40	Wash body	29
Drinking	1	Toilet	34
Brush teeth	26	Housekeeping	3
Brush teeth and face	2	Garden irrigation	1
Brush teeth and wash hands	3	Wash clothes	5
Wash hands	8	Wash dishes	26

Table above shows that drinking was not reported itself, maybe because it is included on the category of cooking, since people used to boil the water they drank. Uses related to hygiene, such as brush teeth and hand washing were reported together. This is probably due to people practices, and in other studies, these uses are not reported separated either, such as Roa (2005), Barrios (2008) and the case of Howard & Bartram (2003), where all water hygiene needs, including personal and household hygiene are reported together.

Wash hands was reported just 8 times and just by three households. Therefore, it is possible that it can be included on brush teeth, or maybe that washing hands is not a common practice among the participants. On the other hand, the reported use of the toilet was also low. According to the Diary´s records and household sizes, one household member used the toilet in average 1 – 2 times a day. It may be explained, because most household members were not at the premises during the day. Although, in the house were the monitoring was carried out directly by the author, just one of the household members used the toilet once during the almost 11 hours that the author was present. Another reason for this underreporting, may be that people felt ashamed to record the actual use. Not all households reported uses like washing clothes, housekeeping and garden irrigation, since these activities are not carried out every day.

Water consumption for different domestic uses: The measurements reported on the diaries were grouped on the next categories:

- Brushing teeth and washing hands
- Bathing
- Washing clothes
- Housekeeping
- Cooking and drinking
- Washing dishes
- Toilet
- Garden irrigation

Results of per capita consumption for these uses are shown in Figure 5-12.

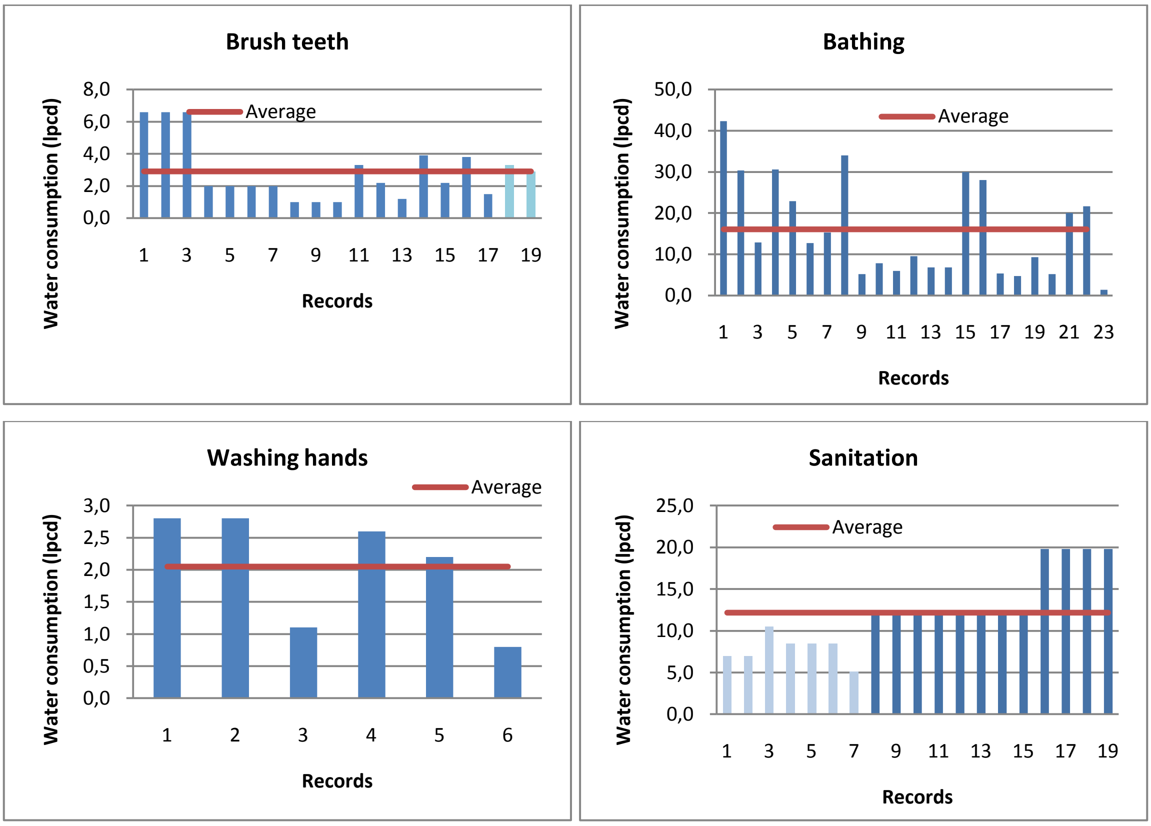


Figure 5-12 Water per capita consumption for personal hygiene and sanitation

Figure 5-12 shows that for brushing teeth the range of values were from 1 to 6 lpcd, with an average of 2,9 lpcd. In this case, the difference on the values may be related to people habits, being the largest volume for people who conducted this activity three times a day. For bathing, values were also variable but they were not related to any aspect such as gender, water abstraction device (container / tap) or people´s age. In the case of washing hands, this per capita figure is probably underreported, since from the 24 people part of this monitoring, this use was registered just for 6 people and generally one single time; except for records 1 and 2, which correspond to two children who washed their hands 4 times each. The other six records are for a single use. In the case of sanitation, the average frequency of reported use was 2 times a day and these values were influenced by the sanitation system. Bars in light green are for pour flush latrines; records in light blue are from low consumption flush-toilets and records in navy blue are from a toilet that discharged 10 L per flush.

For uses like cooking and drinking, washing dishes, washing clothes, housekeeping and garden irrigation, consumption was estimated by adding the total household consumption recorded for these uses. Therefore, the consumption in these categories was calculated just with six or less records and results are shown in Figure 5-13.

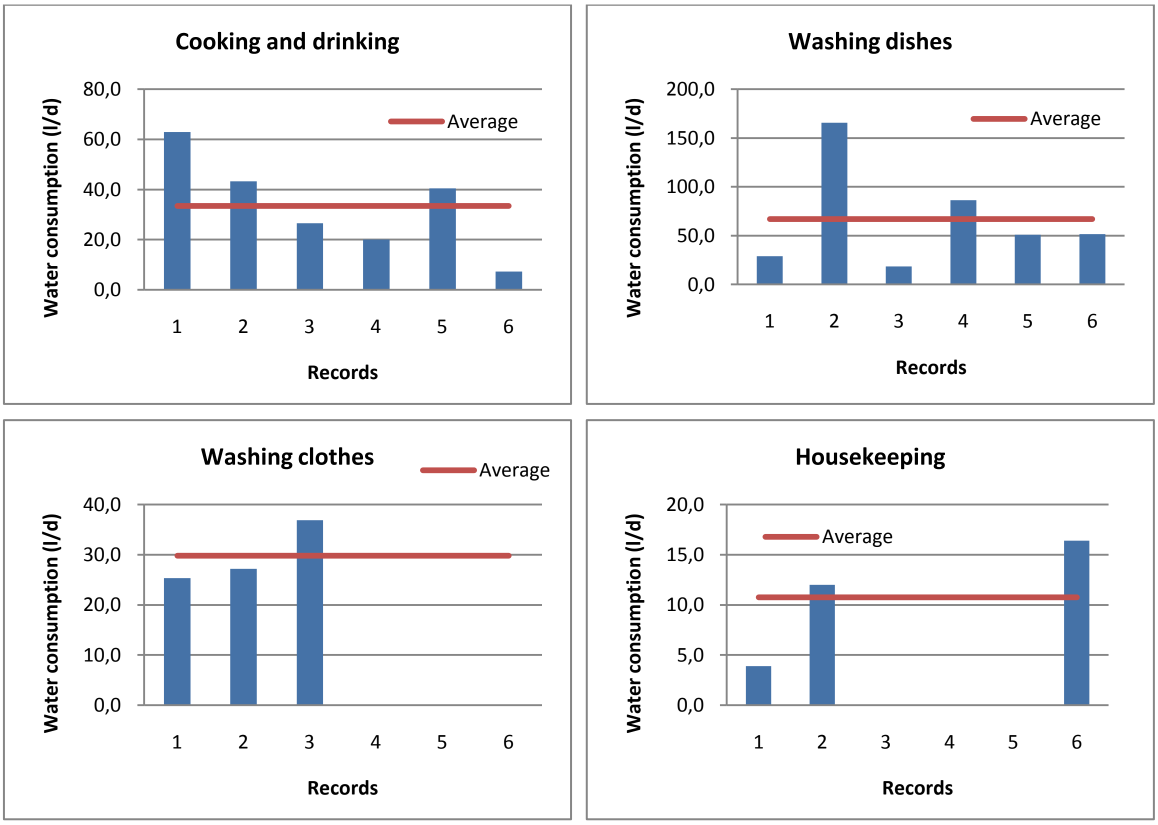


Figure 5-13 Water consumption for uses related to the house

As can be seen from Figure 5-13 water consumption in uses related to the house can be highly variable between the different houses and depend on customs of each family and its daily dynamics. For example, uses such as laundry and housekeeping do not take place every day.

Total domestic water per capita consumption: Total per capita water daily domestic consumption appears on Figure 5-14.

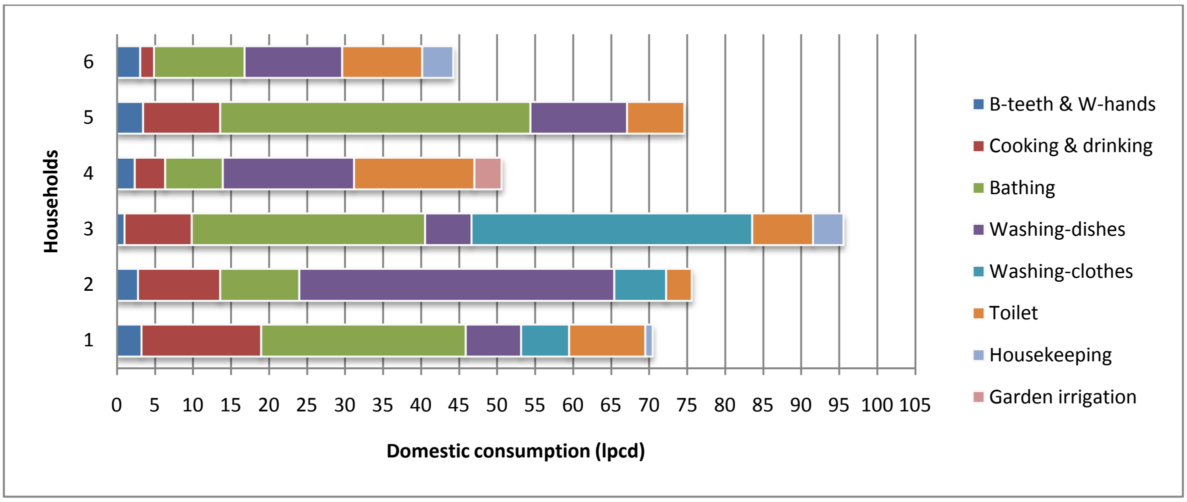


Figure 5-14 Domestic per capita consumption in the six monitored households

Results in Figure 5-14 varied from a minimum of 44,3 lpcd to a maximum of 95,6 lpcd. The data set for any of the households contained all of the reported categories of domestic uses. Households 4 and 6 reported 7/8 uses, households 1, 3 and 5 informed 6/8, while in the home monitored by the author just 5/8 uses were registered. Missing categories of use correspond to those activities that are not performed daily, such as washing clothes, housekeeping and garden irrigation (ornamental plants). These results support which has been stated by Keshavarzi et al. (2006), indicating that water consumption is highly based on some behavioural and cultural aspects.

Among the not recorded uses, washing clothes is a significant water demanding one. For this reason to avoid this situation, monitoring activities like this, should be developed for more than one day or in a bigger number of households. However, in this case, since it was very difficult to achieve people participation, the chances of housewives agreed to fill the diaries for more than one day were really low, and as discussed in the methodology chapter, to get that at least 6 households were involved, was also complicated.

Table 5-3 shows some descriptive statistics of the set of per capita water consumption figures for the six households. Categories, which present the most highly variable water consumption, were bathing and washing dishes. The standard deviation of the total per capita consumption was 18,6 lpcd.

Table 5-3 Descriptive statistics for per capita water domestic consumption data

Category of use	Average	Max	Min	STD
Brushing teeth & Washing hands	2,6	3,5	1,0	0,9
Cooking	8,6	15,7	1,8	5,0
Bathing	21,4	40,8	7,6	13,4
Washing-dishes	11,3	17,3	6,1	4,6
Toilet	9,2	15,8	3,4	4,1
Washing-clothes*	16,7	36,9	6,3	17,5
Housekeeping	3,0	4,1	1,0	1,8
Garden irrigation	3,6	3,6	3,6	
Total domestic per capita consumption	76,4	95,6	44,3	18,6

* Value of 330 lpcd from Household 2 was considered an atypical data and thus was not considerate to calculate this average

Figure 5-15 presents the distribution of the average consumption among different domestic uses. This Figure shows that for the monitored households, bathing represented the largest consumption activity, which contributes to 28% of the per capita demand followed by washing clothes (22%). On the other hand, the uses that consumed less water were brushing teeth and washing hands (3%), housekeeping (4%) and garden irrigation (5%).

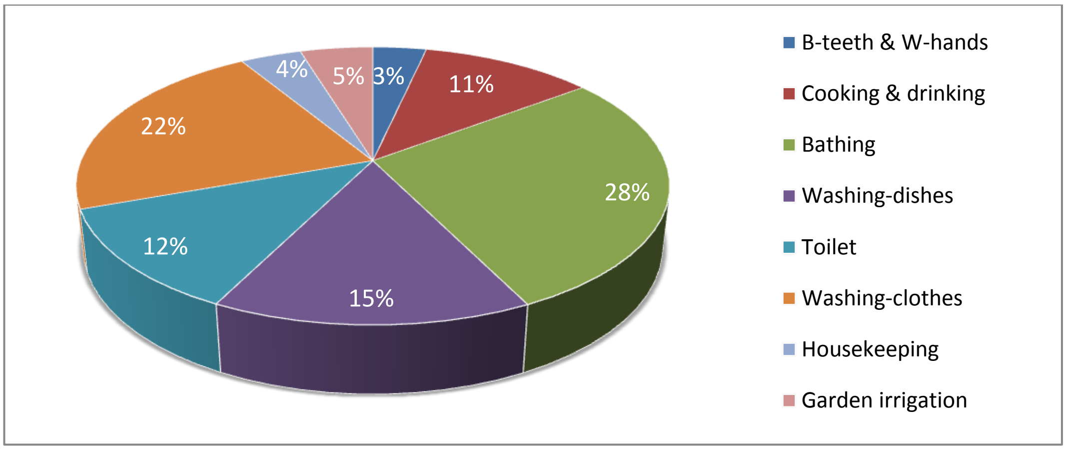


Figure 5-15 Distribution of the domestic water per capita consumption among uses

Table 5-4 compares the collected data against the data from the literature reviewed and as was previously discussed, the sanitation figure is lower (9 lpcd) in comparison to other sources (13 – 41 lpcd). Drinking and food preparation is higher, 9 lpcd compare to the reported average of 4,5 lpcd. The total average water consumption, 77 lpcd, is within the range informed by the literature (50 – 178 lpcd), although due to the limitations discussed in relation to sanitation use, and uses not performed every day, especially washing clothes, this figure maybe higher.

Table 5-4 Comparison between the collected data and the Literature Review

Domestic water uses	Literature [a]		*La Palma Tres Puertas* Average
	Max	Min	
Sanitation(lpcd)	13	41	9
Bathing (lpcd)	12	46	21
Drinking and food preparation (lpcd)	4	5	9
Dish washing (lpcd)	8	28	11
Laundry (lpcd)	16	79	17
Housekeeping (lpcd)	5	5	3
Brush teeth and hand washing (lpcd)	3	5	3
Garden irrigation (lpcd)	--	--	4
Total (lpcd)	50	178	77

a Figures from the Literature review reported in Section 2.6, Table 2.1 from: Gleick (1996), Roman (2002), Nozaic (2002), Roa (2005), Barrios (2008)

The data obtained from this monitoring, in particular, the average total domestic water demand of 77 lpcd, which is lower than that reported by other authors in similar contexts such as Roa (2005) and Barrios (2008), has the following limitations resulting from the methods employed for its estimation:

- The measurements undertook by the author in Household 5 are biased for that kind of bias that Posdakoff et al. (2003) name “social desirability bias”, since participants were affected by the presence of the researcher and thus behave in an unexpected way. For instance, did not use the toilet for almost 11 hours; a young member of this family also decided to spend most of the day out and did not take lunch, or bathed as she stated she felt uncomfortable being observed.
- Another source of error in the same category is that, since family members were active participants in this activity, they were aware of the research objectives and there are chances that they have changed their practices in relation to water use to have a more rational behaviours (reduce the water use).
- Another potential bias in relation to people´s behaviour is that in some cases, i.e. Household 2, family members may have adopted more stringent hygiene practices (i.e. washing hands more frequently, brush teeth three times a day).
- On the other hand, hygienic practices that influence water per capita consumption probably were underreported, such as brushing teeth, washing hands and using the toilet. This may be because people did not spend much time at households, or maybe that

washing hands and brushing teeth habits are rare among the sample population. Another explanation maybe because, since housewives were the main responsible to collect these data, and these activities were carried out for all family members, it could not be registered with the frequency with was actually performed. Although, specific forms for these uses were provided separately to be filled for all people in the house in the areas where water use took place, but just one stopwatch was provided. This may be the reason for the sub-registration in the cases where these activities used a tap as a water abstraction device. However, this also happened where a container was the water abstraction device.

- Another source of error is that to find flows from the taps, those were measured according to the way housewives tend to open them. No measurements were made for other family members. For containers, it is also likely that people would require larger or lower volumes than the volumes set, which also could be a source of bias.

To determine the validity of these measurements, per capita domestic demand was estimated through other means, applying the principle of triangulation, using records from the meters and information from the household survey. Comparison between data measured during monitoring and results from the second approach appear in Table 5-5.

Table 5-5 Comparison between average consumption from two methods of estimation

Estimation Method	Domestic water per capita consumption (lpcd)					
	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6
Monitoring	70,5	75,6	95,6	50,6	74,6	44,3
Meter records + Household survey	86,5	N.A.	100	58,7	116,0	41,7

HH: Household

Data on Table 5-5 shows that monitoring results were close to those obtained from the meter records and household survey in the cases of Households 3, 4 and 6, and even for Household 1. The case of Household 5 where the author carried out the monitoring presents the result with the largest differences between the two methods. Therefore, recognizing all potential errors in the monitoring strategy, it can be said that the water diaries were a better method of collecting this information, and from the way they were submitted, is evident that the housewives were committed to develop the task.

However, as will be discussed further, the domestic water per capita consumption was also calculated with the second approach (meter records + household survey) in 106 households in the system, providing an average figure of 95 lpcd for domestic water consumption. It suggests that values resulting from the monitoring are fair values, maybe in the particular case of the monitored households, but not to the general population. One possible explanation for this is that since this activity was voluntary, possibly people which agreed to take part had a higher level of concern for water protection compared to the rest of the community, which can makes their per capita consumption lower.

77 lpcd and even 95 lpcd are within the range that the Colombian standard (RAS - 2000) allows for designing of rural water supply systems for domestic purposes 100-150 lpcd. However, as shown from the information presented on the characteristics of the households of *La Palma Tres Puertas* system, only 17% of people served have exclusively domestic uses, while the remaining 83% develop productive activities that depend on water, therefore, the total household water needs, exceed the amounts suggested by this standard.

5.3 Water balances at the system and household level, including water demand for multiple uses, and water inputs, considering blue water and green water

This section presents and discusses the results of the activities undertaken to address Objective 3: To propose balances at the system and household level, including water demand for multiple uses and water availability, considering blue water and green water.

As discussed in previous sections, people in rural areas use water supply systems for multiple uses. However, these uses depend on several water sources which are used simultaneously (Scheelbeek, 2005; Van Koppen et al., 2009; van Koppen & Smits, 2010; Mikhail, 2010). Similarly, most small farmers in developing countries, especially in Latin America, produce their crops under rainfed systems (Molden et al., 2007), which eventually require additional water inputs to meet crop needs at special stages of development or during short dry-spells (Sulser et al, 2009). To try to look at these aspects from an integral perspective in a MUS system, water accounting tools based on water balance concepts (Perry, 1996; Molden, 1997; Rosengrat et al., 2002; Ratnaweera et al., 2006; Haley et al., 2007) were used in the present case study of *La Palma Tres Puertas* water supply system. The results are presented and discussed below.

5.3.1 Water balance domain

Figure 5-16 presents the study area with the villages of *La Palma*, *Tres Puertas* and *Buenvivir*. It also includes the pipes of the water supply system, which has been plotted over this political map, and appear in purple.

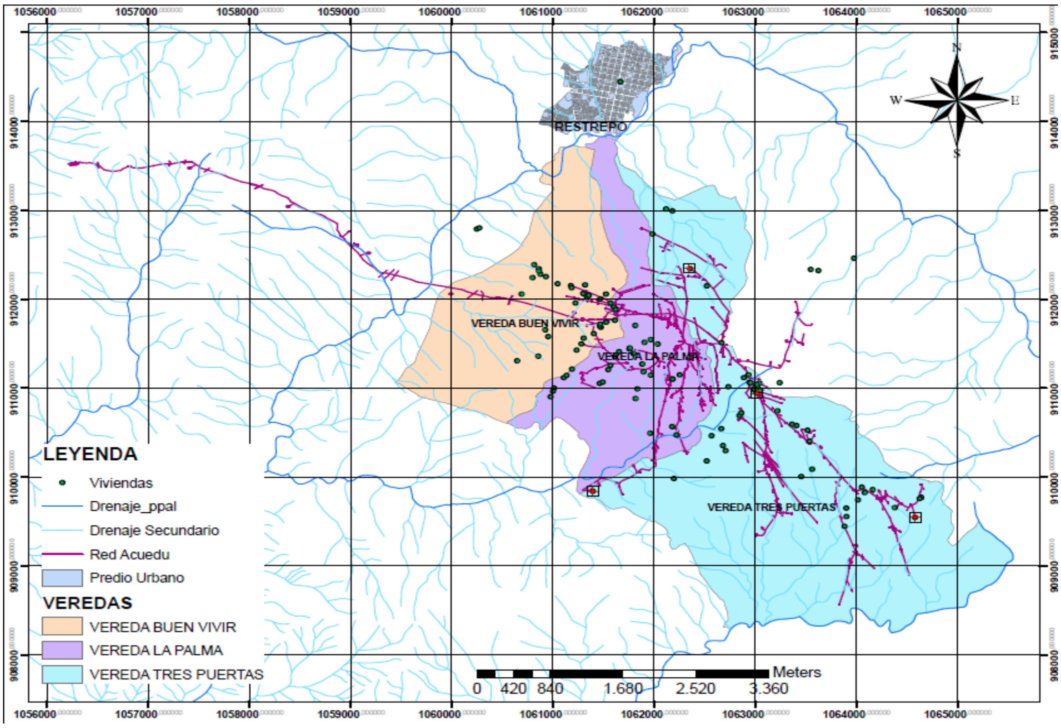


Figure 5-16 Map of the study area (Portilla, & Rendon, 2010)

Settlements of *Colegurre*, *Chontaduro* and *Ventaquemada* belong to *Tres Puertas*; *Monteredondo* belongs to *La Palma*, and *El Agrado* is part of San Pablo village, which is not coloured, although, the pipelines appear on the white background at North East. Green points are some of the surveyed households, which were geo-referenced during the fieldwork period. At North the town of the municipality to which the villages belong appears, and at Northwest, the area where the system intakes are located. Except for the area where the water is taken (*Sabaletas* sub-basin), the rest belongs to *Aguamona* sub-basin which drains Southwest.

The spatial boundaries selected in order to apply the conservation of mass principle (Molden, 1997) to perform the water balance appear in Figure 5-17. In this Figure, the area of interest is shown on a green background and contains the households served by the system. For this balance, two levels of analysis were set, a level which includes the households which are customers of the water supply system as a whole (106[9]), called "system level" and a second level, a sort of "zoom" to each served household, called "household level". The diagram shows the inputs considered for the water balance analysis, represented by the rain that falls on the study area, and the second inflow is the water transferred from *Sabaletas* sub-basin, which is the water supplied by the system. The green circle on the sketch represents the "zoom" to households and shows the water outflows in the balance, which are basically the water

[9] 106 dwellings are part of the 134 homes surveyed that were characterized on aspects related to poverty, livelihoods and access to water. The number was reduced, because for the 28 homes that make the difference was not possible to balance the water used for productive activities theoretically calculated from the household survey, to the record meters of water consumption for these households during the analysis period

consumption for multiple purposes. Other outputs considered were infiltration and downstream flows, which also appear on the sketch.

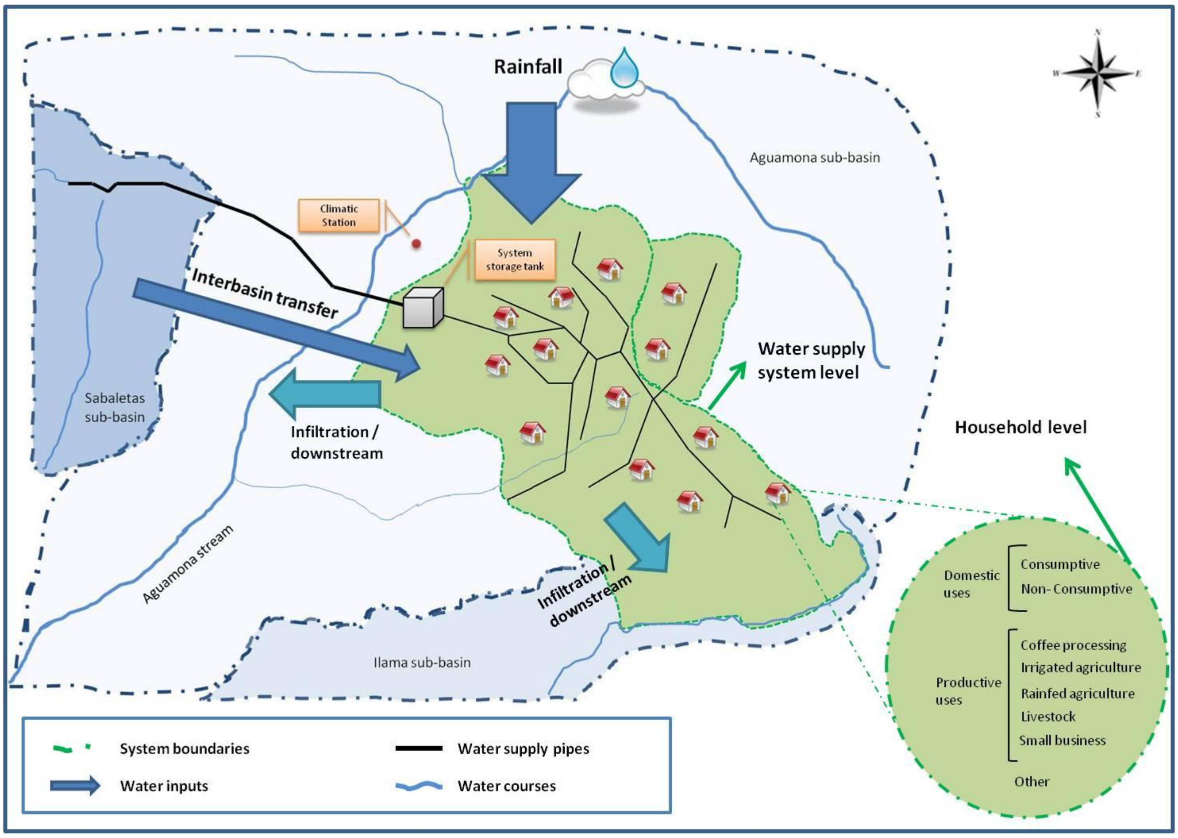


Figure 5-17 System boundaries for the water balance

The temporal boundaries were defined as the months of May and June 2010 where most of the information regarding to inflows and outflows was available to apply the conservation of mass principle (Molden, 1997).

5.3.2 Water balance estimation

Inflows: The household survey confirmed the information from Cinara (2006) and Ospina (2009) about the water sources used in the area, indicating those were mainly the water coming through the water supply system and the rainfall. Water from the water supply system was the main source for all domestic uses. i.e. 99,3% of the interviewees used this water for personal hygiene, and 98,5% for drinking and cooking. 0,7% use springs and 0,7% bought bottle water for drinking. From the 99% that indicated to use the system for domestic purposes, 7% expressed that eventually, they used other sources such as rainwater and springs, although, the water supply system was the main source. To illustrate the case of productive activities, most households used the water from the water supply system, except for a 2%, which used private wells or springs to complement livestock needs. From the 16% that grew maize, 45% irrigated it with the water supplied by the system, 100% of the 7% that grew vegetables and the 2% of those, which grew *lulo*. Other crops, such as coffee, pineapple and *pitaya* were rainfed crops.

These results confirmed that the analyzed households were supplied mainly from the system for all domestic purposes and for uses such as drinking and cleaning livestock, coffee processing and supplemental irrigation of some crops. Crops water needs were met mainly by rain. In rare cases, additional sources like private springs or bottled water were used for domestic purposes such as drinking. In some areas, where water reduces during strong dry seasons, maybe due to technical reasons, few people moved to a spring (about a one or half hour round trip). Few households had springs or wells on their properties (2%) and combined the use of this water with water from the system. In general, the use of supplementary sources was marginal or sporadic.

Water supply inflow: The water entering to the centralized storage tank of *La Palma Tres Puertas* system coming from the two small streams, *Tobón and Sinaí*, was measured five times during July 2010. Results from these measurements are shown in Figure 5-18. Volume supplied was calculated as the average of the data taken. The measures were considered representative for the analysis period. The average inflow was 5,2 l/s with a standard deviation of 0,5 l/s.

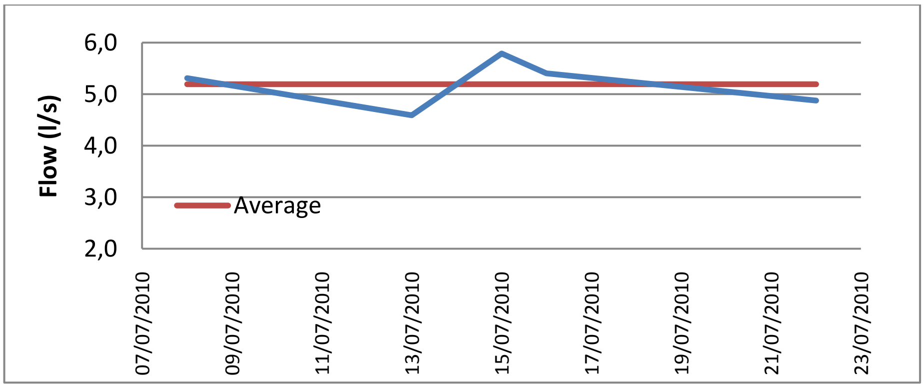


Figure 5-18 Inflow from the water supply system (inter-basin transfer)

For the analysis period, this inflow represents a volume of 26957 m^3. Although, this volume provide the whole 437 customers of the water supply system, not only the sample of 106 customers (24% of the total). The water consumption for the 106 households reported by the meter records for the analysis period was 6064 m^3; 22% of the total flow entering from the water supply system. These figures (24% and 22%) were closed, and may suggest that water supplied by the system may meet the demands of these users at this time. Although, the meter data covered the period May-June 2010, and the input data of the storage tank were taken during July 2010, as shown below in Figure 5-20, the month of July is still representative of dry season conditions.

This result indicates that the water available during dry season for the whole population is 5,2 l/s. The study carried out by Ospina (2009) in the same area indicates that 62 households will require about 7 l/s to satisfy their water needs for multiple purposes. The scope of Ospina´s study was on the demand side. The information presented may suggest that people have accommodated their water needs for multiple purposes to the water available at the system.

Rainfall: Precipitation for the analysis period was provided by Cenicafé from records of *Julio Fernandez* Climate Station and is shown in Figure 5-19. During the 61 days period, there were 25 days of rain and 72% of the total precipitation fell in 5 episodes.

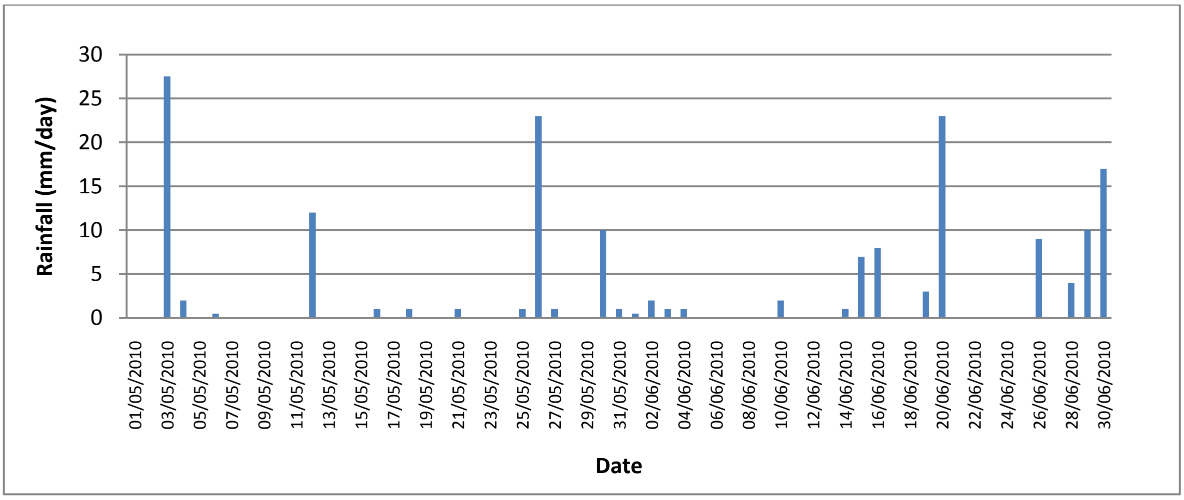


Figure 5-19 Daily rainfall data for the analysis period (Cenicafé, 2010)

Although, the historical daily average rainfall was not available for this study, if this behaviour follows the pattern shown in Figure 5-19, the available rain does not fall evenly over time, and therefore it is possible that crops, major users of this flow, cannot use this resource properly and therefore do not have optimal yields.

Total rainfall during the period was 169,5 mm distributed 81 mm in may 2010 and 88,5 mm in June 2010. Figure 5-20 compares the rainfall during the analysis period with the average rainfall in the area taken from Ospina (2009) who estimated this pattern analyzing data from a ten-year period (1990 – 2000). Figure also tells about the bimodal pattern of rainfall in the area with two wet and two dry seasons. This pattern is typical of the Andean Region in Colombia (Rosales, 2001).

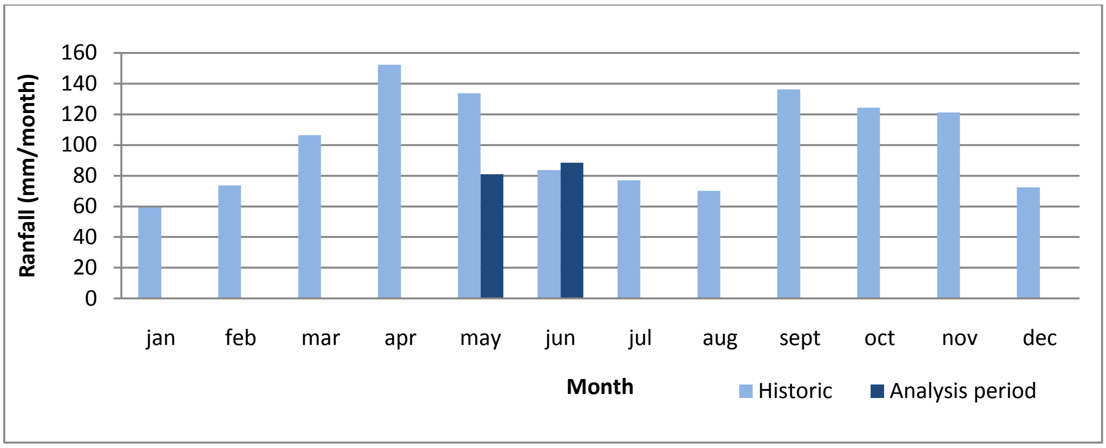


Figure 5-20 Monthly historical data and monthly data for the analysis period

The Figure shows how rainfall in May 2010 was about 30% less than the average conditions, and June 2010 was close to the average pattern. In total, for the analyzed two months, it rained less compared with the historical average. However, because apparently the rains were torrential, many locals expressed that "it's raining more", and many of the interviewed indicated that periods they used to seed in the past, do not fit to the current situation and therefore they do not know when it is the dry season, and when the wet season. This can be a problematic situation, especially for households in stratum 2[10] who rely more on rainfall for their agricultural activities.

Water inflow from rainfall into the domain is presented on Table 5-6 according to strata. The Table shows how people in stratum 2 have slightly more inflow from the rainfall since they had 52% of the total area considered. People in stratum 3 had 46% of the area and therefore, an equivalent proportion of rainfall.

Table 5-6 Water inflow from rainfall

Stratum	Area (m^2)	Rainfall (m^3)
1	52.049	8.822
2	1.388.707	235.386
3	1.220.429	206.863
Total	**2.661.185**	**451.071**

Table 5-6 shows how, although users in stratum 3 were only 16% of total households, as they had more land (46% of total), they had almost the same potential to benefit from the rain as do all households in stratum 2 together (52% of total area).

[10] Strata are based on consumption level of subscribers of the water supply system. Strata definition is detailed on the methods chapter

Outflows: Outflows were calculated for water consumption, according to categories of domestic and productive use; the latter divided into Livestock Consumption, Coffee Processing Consumption, Crops Consumption and Other (Small Business and Swimming Pools). Water consumption for crops was calculated as Blue Water Consumption (water supply system) and Green Water Consumption (rainfall). All data are presented in volume (m^3) for the analysis period (May – June 2010). The information includes the volume per stratum and the total volume. The approach to define categories of consumption and blue and green water availability was described on the methodology chapter (See Table 4-9, Equation 4-4, Equation 4-6).

Table 5-7 shows the domestic consumption outflow, which depends on the household size, understood as the number of people within a household, and per capita water consumption. Total volume consumed for this purpose was 2421 m^3, from which 71% was consumed by people in stratum 2, which had the bulk of the population within the sample.

Table 5-7 Domestic consumption

Stratum	Households	Total inhabitants	Total consumption (m^3)
1	16	36	183
2	73	309	1768
3	17	78	470
Total	**106**	**423**	**2.421**

Table 5-8 presents livestock consumption, which was mainly due to the presence of chickens, pigs, cows, horses and in a minor scale other (rabbits, ducks and guinea pigs). Number of animals per species appears on the Table and total livestock consumption, according to stratum. Volumes include the required amount of water for drinking and cleaning purposes. 66% of the water livestock consumption was due to the 17 households on stratum 3, 32% for households in stratum 2 and 1% of households in stratum 1.

Table 5-8 Livestock consumption

Stratum	Units					Total consumption (m^3)
	pigs	chicken	cows	horses	Other	
1	0	55	6	0	8	18
2	34	520	162	28	71	416
3	165	4193	236	39	0	860
Total	**199**	**4.768**	**404**	**67**	**79**	**1.294**

Table 5-9 shows cropped areas with coffee and water consumption due to coffee processing. Households on stratum 2 accounted for 68% of the areas cropped with coffee and since the water consumption for this activity, according to the assumptions made, depends mainly on the area, the same proportion was their water consumption for this use.

Table 5-9 Coffee processing consumption

Stratum	Cropped area (m^2)	Total consumption (m^3)
1	7.100	10
2	216.133	303
3	94.800	133
Total	**318.033**	**445**

Table 5-10 presents other uses consumption. Those were identified in 3 houses within stratum 2 and represent water consumption about only 122 m^3.

Table 5-10 Other uses consumption

Stratum	Units		Total consumption (m^3)
	Business	Swimming Pools	
1	-	-	-
2	2	1	122
3	-	-	-
Total	**2**	**1**	**122**

The figures presented indicates that households in stratum 2, which are 71% of the total population served by the water supply system, as result consumed more water for domestic purposes. The estimates of water consumption for livestock shows that households in stratum 3, 16% of the total, used most water for this purpose (66%), and this consumption was mainly due to cattle. These 17 households had 1.5 times more cattle than the 73 households in stratum 2, and 39 times more than 16 households had in stratum 1. Households in stratum 2 grew more coffee than households in other stratums and therefore they had a higher consumption of water for this use. Estimates of water consumption for coffee processing correspond to the "traviesa" (refer to methods chapter), whose production is only a quarter of the annual coffee harvest. Therefore, this value is not critical for water consumption for this activity and it may increase approximately 3 - 4 times during the major coffee harvest from September to November. However, these months are wet season and the increase in this consumption may be balanced with the reduction in other uses consumption.

Blue Water Consumption for crops (irrigation and fumigation) appears on Table 5-11. This only includes crops and areas where surveyed people indicated they did irrigate/fumigate crops using the water from the water supply system.

Table 5-11 Blue water consumption by crops (irrigation and fumigation)

Stratum	Area (m^2)*	Total consumption (m^3)
1	6.502	19
2	239.261	590
3	159.429	1.173
Total	**405.192**	**1.782**

* It includes only the areas which belong to people, which expressed they irrigate within the household survey

According to these results in stratum 2 people grew 59% of the area with irrigated crops and consumed 33% of the water from the water supply system to supplement crop requirements, while 39% of the area was grown with these types of crops in stratum 3 and accounted for 65% of the total water crop consumption from the water supply system. Although, fumigation was included in the estimations, this consumption was less than 1% of the total water households consumption in the majority of the cases.

Those figures suggests the need to improve the information in which assumptions that underlie the water consumption estimations, using the water balance approach were carried out. Although, in general terms, farmers have similar practices, there are differences: some irrigated, some did not, the frequency and amounts of water applied could change and this also depends on whether the crop was for sale or self-consumption (i.e. maize). For instance, much of the area presented in Table 5-11 as area under irrigation in stratum 3 is pineapple, which is not irrigated, and the use of fumigation is not significant. Therefore, irrigation consumption estimation may include livestock consumption, in cases where pineapple farmers have cattle, and even more if most of these cattle were dairy rather than meat (which was not asked). Then, consumption of cows to some users might be under-estimated and irrigation oversized. This may happen since to balance inflows and outflows for the final calculation, water use for irrigation depended not on the area cropped, but on the surplus obtained by subtracting to the total household consumption, the domestic, livestock, coffee processing, etc. (in households whit crops). Furthermore, most of the 28 customers who were removed from the sample to "balance the equation" belonged to stratum 3.

The examples shown above indicate that assumptions made, may be more reliable for households in stratum 2 and 1, and the difficulty with large water consumers. These large water consumers have a more complex use of water, since usually they develop productive activities simultaneously, their production systems are more varied, in some cases more “sophisticated”, have storage tanks with higher capacities, or even marginally, some may use additional water sources.

Green water consumption for irrigated crops and rainfed crops is shown in Table 5-12. It illustrates about the proportion of the rainfed agriculture in the area. Area cropped with rainfed crops was 3,5 times area cropped with crops that require irrigation in the stratum 2 and 19 times for stratum 3. From the total consumption of green water, people in stratum 2 accounted for 54% and people in stratum 3 for 44%.

Table 5-12 Green water consumption by crops

Stratum	Irrigated crops		Rainfed crops		Total consumption (m^3)
	Area* (m^2)	Volume (m^3/period)	Area (m^2)	Volume (m^3/period)	
1	12.877	1.889	39.152	4.465	6.354
2	312.044	36.924	1.076.663	134.542	171.466
3	61.029	8.941	1.159.400	129.337	138.277
Total	**385.950**	**47.755**	**2.275.215**	**268.343**	**316.098**

* It includes the cropped areas where estimation of water requirements according to Allen et al. (1998) & Brouwer et al. (1992) indicates water from rainfall was not enough to supply crop needs

A significant proportion of the land owned by those in stratum 3 was under pastures; therefore, the proportion of green water consumption in rainfed agriculture exceeded the green water for irrigated crops in this stratum. Most areas under rainfed agriculture for households in stratum 2 are under coffee. This suggests the importance of green water for these households since this is basically the asset for them to produce crops and get their income. Besides, their dependence on the water supply system is lower compared to users in stratum 3. This may be consistent with the views expressed by Molden et al. (2007) who indicate that in Latin America about 90% of the permanent crops such as coffee, and annuals such as maize, are under rainfed agriculture.

Other water balance components estimation:

Return flows, drainage and deep percolation appear in Table 5-13. Stratum 2 was the largest producer of return flows and runoff. Stratum 3 was the largest producer of downstream /infiltration since the 73 of households in this stratum accounted for the largest area served by the water supply system.

Table 5-13 Other water balance components

Stratum	Return flows (m^3)	Runoff (m^3)	Infiltration/ Downstream (m^3)
1	156	1197	1271
2	1758	31940	31979
3	707	28069	40516
Total	**2.621**	**61.207**	**73.766**

The components of the water balance according to categories of use and stratum are summarized in Table 5-14. All figures are reported in volume (m^3) for the analysis period. The way all the components were calculated was described on Chapter 4 (methods) and the spreadsheets with the estimations are included in Appendix C.

Table 5-14 Summary of Water Balance Components*

	Stratum 1	Stratum 2	Stratum 3	Total
Inflows				
Rainfall	8.822	235.386	206.863	451.071
Water supply system	229	3.200	2.636	6.065
Total inflows	**9.051**	**238.586**	**209.499**	**457.136**
Outflows				
Domestic	183	1.768	470	2.421
Livestock	18	416	860	1.294
Coffee processing	10	303	133	445
Blue water irrigated crops	19	590	1.173	1.782
Other uses	-	122	-	122
Green water irrigated crops	1.889	36.924	8.941	47.755
Green water rainfed crops	4.465	134.542	129.337	268.343
Other				
Return flows	156	1758	707	2621
Runoff	1.197	31.940	28.070	61.207
Infiltration/downstream uses	1.271	31.979	40.516	389.864
Total outflows	**9.051**	**238.585**	**209.499**	**457.136**

* All Figures are in m^3 for the period May – June 2010

Table 5-14 shows how rainfall is the main inflow to this system. The water supply system just accounted globally as the 1,3% of the total water available for these households. Despite this fact, this 1,3% represented 100% for domestic consumption, livestock consumption, coffee processing and other uses. The system provided 3,6% of the requirements for crops which needs cannot be satisfied entirely by rainfall. Although, comparing this volume with the inflow provided by the water supply system, these quantities were equivalent to 8%, 18% and 44% respectively. Thus, in this system occurs what Sulser et al. (2009) express in the sense that blue water is used in production systems classified as rainfed, involving applications of supplemental water in special stages of their plant´s production cycle or during short term dry spells.

The 73 households on Stratum 2 used more water from the water supply system for domestic uses, coffee processing, small business and pools, while 17 households of stratum 3 used more water from this system for livestock and irrigation.

The distribution of the total input into the system is shown in Figure 5-21. To the left the distribution of the water supply system into the different categories of use is shown. Domestic uses accounted for 40% of the total consumption, 2% for uses such as small business and swimming pools and the remaining 60% was distributed in productive uses: 30% as supplemental irrigation, 21% for livestock, 7% for coffee processing. To the right the distribution of the rainfall inflow is shown: rainfed crops used 59% of the water that fell and irrigated crops 11%. The remaining 30% went to runoff, infiltration and downstream.

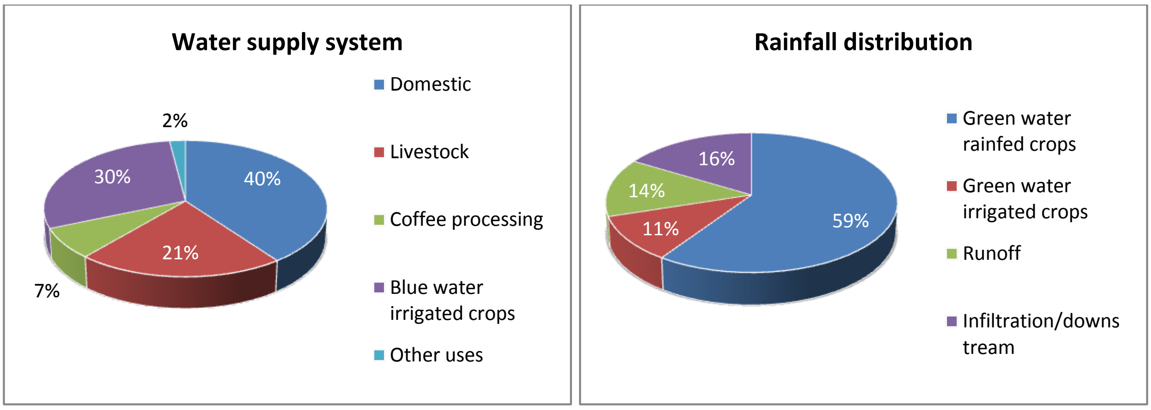
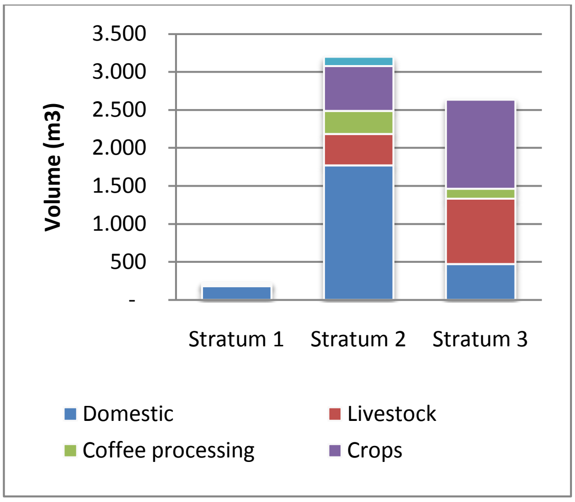


Figure 5-21 Global distribution of inflows according to categories of use

Figure 5-22 shows how inputs from the water supply system and the rain are distributed for categories and strata. At the left inputs from the system are shown and at right inputs from rainfall.

Figure at the left indicates that the 73 households on stratum 2 consumed most of the water supplied from the system, especially for domestic purposes (about 55%) followed by crops (about 20%) and livestock (about 10%). Although, quantities for those last uses (590 m^3 and 416 m^3) are smaller compared to the volumes consumed for those categories by the 17 households on stratum 3 (1173 m^3 and 860 m^3). In this stratum, the quantity of water for domestic use was less than 20% (470 m^3). In stratum 1, about 80% of water consumption was for domestic purposes and for the 16 households the total water consumed was 229 m^3.



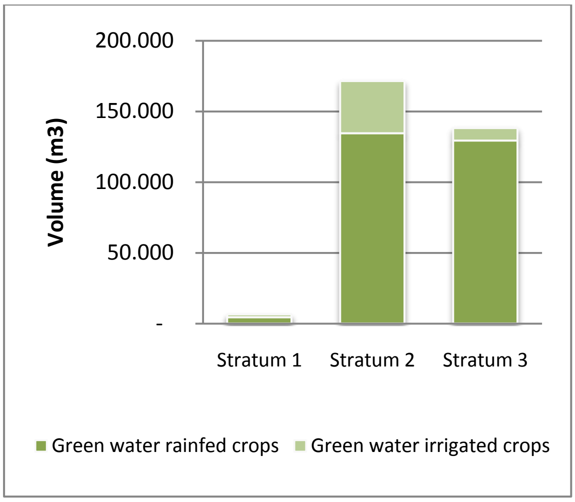


Figure 5-22 Distribution of inflows according to categories of use and stratum.
Left: inputs from water supply system. Right: inputs from rainfall

Regarding inputs from rain, which are used mainly for crops, Figure 5-22 (right) shows that the bulk of inputs from rainfall are used mainly for rainfed crops, similar volumes on strata 2 and 3 (134542 m^3 y 129337 m^3). The volume of green-water used by irrigated crops was greater in stratum 2 (36924 m^3) compared to the volume used in stratum 3 (8941 m^3). This is because the area planted with these crops for the total households in stratum 2 is approximately five times greater than in stratum 3, and because these crops had greater water requirements. This contrasts with the volume of water from the water supply system used in both strata for these crops, possibly indicating that while households in stratum 3 applied supplementary irrigation to these, those in stratum 2 did not. The use of green water in stratum 1 just accounted for 6354 m^3 for both type of crops.

Summarizing

The water inputs for the three categories of households served by *La Palma Tres Puertas* system were given mainly by rain and the sub-basin transfer from *Sabaletas* coming through the water supply system. Households in stratum 1 used the water almost exclusively for domestic and some productive uses that were marginal or no significant to the water supply system or rainwater. In absolute terms, the 73 users who belonged to stratum 2 used more water from the water supply system and more rainwater than users in stratum 3. Overall, they had the largest population, which directly influenced water consumption and had a greater cumulative area. In this area, these households had mainly crops such as coffee that relied exclusively on rainfall for its development, and supplemental irrigation occurred in isolated cases (smaller areas planted with maize, vegetables, etc). The number of animals that all these households had was 50% the amount households in stratum 3 had. In this stratum as there was a large proportion of small coffee growers, water consumption for the processing of grain was about over double for the same activity used by households in stratum 3.

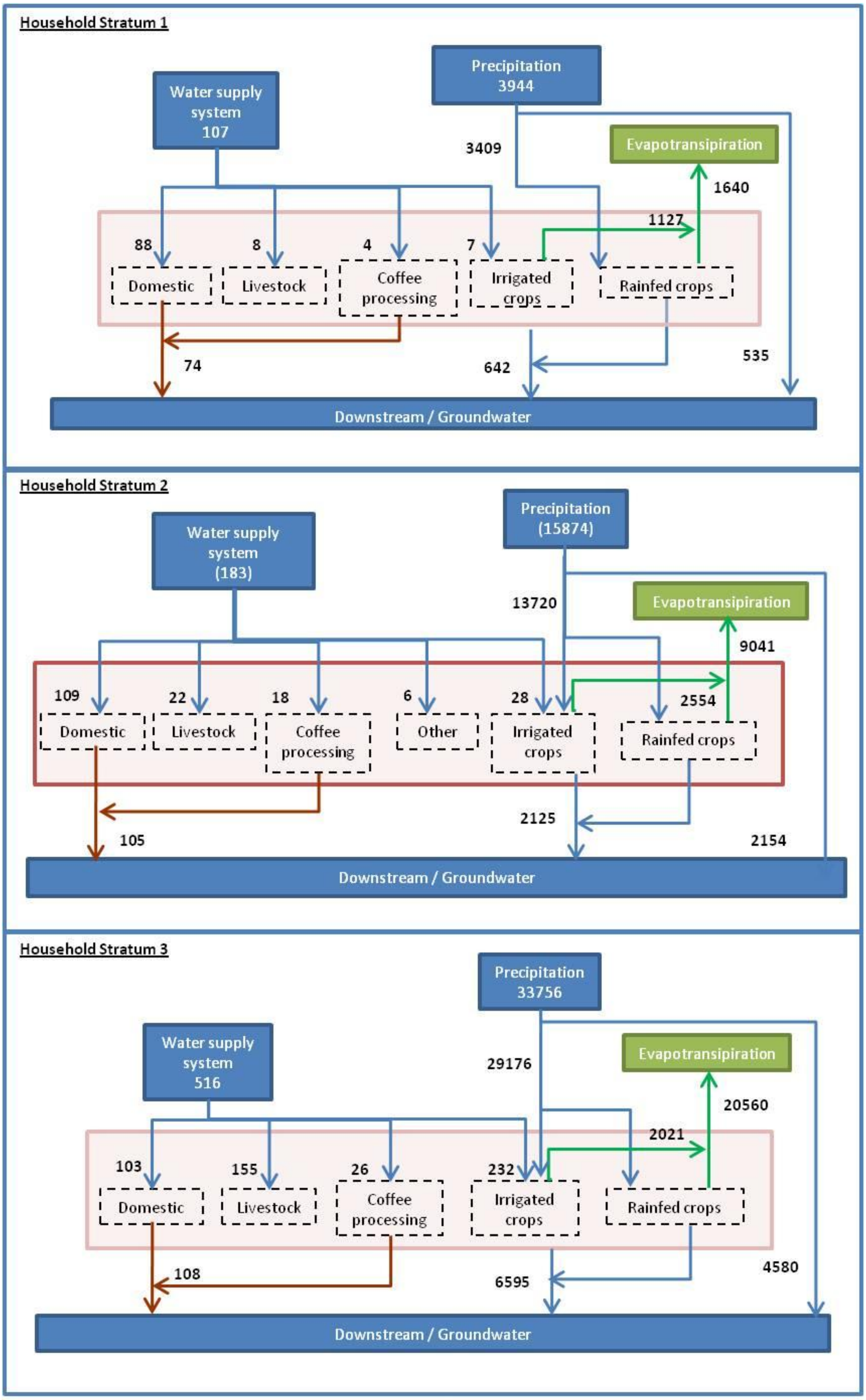
In stratum 3 with only 17 households, the area they had was comparable to that of the 73 households in stratum 2, which allowed them a potential to benefit from the rainwater as much as households in stratum 2 altogether. The same applied with the water from the water supply system these 17 users consumed, 43% of water supplied, while in stratum 2 the 73 users consumed 53%. Most of the water consumed by households in stratum 3 was for productive activities, irrigation and animal husbandry. This is similar to the findings of Smits et al. (2010) in Honduras where households categorized as cattle ranchers have the highest consumption levels year-round.

Although, in stratum 2 was a larger area planted with crops that require irrigation, presumably, these crops are for home consumption and consequently the proportion of water from the water supply system used for irrigation was lower compared to that in stratum 3. However, as explained before, due to the assumptions for the balance, water consumption for irrigation in stratum 3 might include some of the water used for animals. In general, what is perceived, is households in stratum 2 highly depended on rain, and despite these people used the water supply system for some productive purposes, a 55% of the total was still used for purely domestic uses. In contrary, users in stratum 3 used only 18% of the total, for domestic purposes and the remaining percentage for productive activities.

Water balance at the household level

The estimated volumes for the different categories of consumption were expressed as average domestic daily per capita consumption, and average productive daily per capita consumption, according to strata, and the different categories of productive use: livestock, coffee processing, irrigated crops, rainfed crops;. Results are shown schematically in Figure 5-23. This is intended to "*transfer the multiple water needs into water demand characteristics*" as suggested by van Koppen et al. (2009).

For each stratum, Figure 5-23 shows the water inputs: water supply system and rainfall at the top, and their distribution: the water supply system to supply domestic, livestock, coffee processing, other uses and for supplemental irrigation; and the rainfall for irrigated and rainfed crops. Water used by irrigated and rainfed crops left the system as evapotranspiration. A proportion of domestic consumption, livestock and coffee processing became return flows. Part of the rainfall, which was not used by crops, changed to runoff, infiltration and downstream uses. All Figures are given in litres per capita per day (lpcd).



Note: All Figures are expressed as litres per capita day (lpcd)

Figure 5-23 Water balance at the household level

Figure 5-23 shows that inputs from the water supply system and rainfall increased according to the strata identified. Per capita domestic consumption varied few within the three strata in a range from 88 to 109 lpcd. Livestock consumption increased from 8 lpcd in stratum 1 to 22 lpcd in stratum 2 to 155 lpcd in stratum 3. Coffee processing increased from 4 lpcd in stratum 1 to 26 in stratum 3. In general, for productive purposes the water per capita consumption moved from 19 lpcd in stratum 1 to 74 lpcd in stratum 2 to 413 lpcd in the stratum 3.

Based on the quantity consumed for productive uses in strata 1 (19 lpcd) and 2 (74 lpcd), it could be said in line with van Koppen et al. (2009) that "*water quantities required for small scale productive activities, vital for livelihoods are minor, if not negligible*..". However, the average quantity required for productive uses in stratum 3 is not negligible, and the chances of these consumption levels to be absorbed for a water supply system designed under the Colombian standard (100 – 150 lpcd), if everybody would have the same possibilities to use the water, would be difficult and may have impact on the system sustainability. However, in *La Palma Tres Puertas*, users with these levels of consumption are few and water requirements for most people can be supplied with an average of 183 lpcd. Although, these 183 lpcd are slightly higher than the Colombian standard.

Concerning green water, the amount used, also increases according to the different strata. In the case of crops that require supplemental irrigation, the consumption ranged from 1127 lpcd in stratum 1 to 2554 lpcd in stratum 2 to 2021 lpcd in stratum 3. For rainfed crops, it varied from 1640 lpcd (stratum 1) to 9041 lpcd (stratum 2) to 20560 lpcd (stratum 3). It is explained by the increase in household areas as stratum increases and suggests the significance of rainfall for people´s livelihoods in *La Palma Tres Puertas*.

Table 5-15 includes a comparison between the results obtained with results reported by other authors for MUS systems with household connections.

Table 5-15 Water quantities for MUS systems according to different authors

Source	Country	Domestic consumption (lpcd)		Productive consumption (lpcd)	
		Min	Max	Min	Max
Roa & Brown (2009)	Colombia	62	85		250[a]
Smits et al. (2010)	Honduras	45	110	3	484
Mikhail (2010)	Nepal	45 [b]		80 [c]	160 [c]
This study	Colombia	88	109	19	413

[a] Allowing for irrigation and coffee processing. [b] Includes an allowance for livestock as part of domestic use. c From a figure that report total per household assuming 5 as household size. From a system designed for MUS and includes water needs to irrigate a plot from 100 – 200 m^2 with selected crops

Domestic consumption for *La Palma Tres Puertas* estimated through the water balance method, is higher compare to that reported by Roa & Brown (2009) and Mikhail (2010). Although, in all cases domestic figures are less than 110 lpcd. Where differences appear larger is compared to the case of Nepal. This may be explained because the system of Nepal considers the irrigation of vegetables in small plots (100 - 200 m^2) and a domestic allocation of 45 lpcd, including water for livestock. These 45 lpcd are roughly equivalent to the consumption used in this study for the daily needs of one cow.

Productive activities reported in this research are similar to those in the study of Smits et al. (2010) in Honduras, and Roa & Brown (2009) in Colombia, which are related to coffee production, other crops, and animal husbandry as well. Consumptions from Roa and Brown (2009) are smaller although, they suggested in this study area, people have suffered water scarcity and they tend to use water in an efficient way. Smits et al. (2010) in Honduras, studied water use for productive purposes and found differences in the amount of water used for productive purposes between different household categories set according to occupation of household head (i.e., labourers, small farmers, ranchers). As shown in Table 5-15 those differences are on the range from 3 – 484 lpcd. They concluded that a variety of measures which can facilitate multiple use without causing sustainability problems need to be accommodated, such as regulating water consumption, with clear differentiation between consumption patterns and user groups.

While recognizing this information is illustrative, is also important to highlight the limitations in the way it was estimated. In addition to the limitations described on the Methodology chapter, the values shown in Figure 5-23 are estimates based on averages, therefore, those include the effect of maximum and minimum values (i.e. some users without cows averaged with users with 50 cows), thus per capita demand can vary for every purpose, especially in stratum 3. However, since domestic use is less variable, the total productive use is in the ranges listed, what may change is how it is distributed according to the livelihoods of each particular household. Those details appear on the spreadsheets presented on Appendix C.

6 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the key points that can be drawn from the results of this investigation in response to the objectives and research questions raised, and discussed to what extent those objectives were achieved. The appropriateness of the methodologies used is also discussed. Finally, the chapter contains recommendations for future research, especially in the study area.

Conclusions around objective 1: To characterize groups of households within a MUS system according to aspects related to poverty, productive activities, livelihoods and access to water

Different groups of households within the system were characterized, and relations were established between water consumption levels and aspects of poverty, livelihoods and equity; concepts on which the MUS approach is based. Water consumption levels were mainly related to household size, household area, household head occupation, and consequently, to the type and scale of productive activities carried out at the homestead, and to other aspects such as household storage.

It was found that indeed, those households with water consumption under 20 m^3/every two months (stratum 1), used the water supply system primarily for domestic use. There are various reasons for this and the present study did not establish which was the most influential. Some of the reasons are that families were small, or livelihoods did not depend directly from the system, or had small areas, they were not owners, service was provided less frequently and storage capacity was smaller. Households with consumption levels between 40-80 m^3/every two months (stratum 2), had productive activities in farms under 5 hectares, although these activities were dependent on rainfall rather than on piped water. However, some farmers with larger areas or commercial activities, also had this level of consumption, although, those were engaged on activities under systems which use water more efficiently. Households with consumption over 80 m^3/every two months (stratum 3) simultaneously performed various productive activities, like agriculture and animal husbandry. Especially, they had a greater number of animals and properties with larger areas compared to households with lower levels of consumption.

In *La Palma Tres Puertas*, though all residents had the water service, this was intermittent, and for this reason, it was provided by shifts, leading to some inequalities in the access to the resource. It was found that households with water consumption up to 20 m^3/every two months had storage tanks up to 10 m^3, and some of the households with higher consumption, more than 80 m^3/two every two months, had storage tanks up to 100 m^3, especially those who developed larger-scale agricultural activities. This suggests that when the livelihoods of people depend significantly on the water supply system, they are willing to make major investments to have water in a more reliable way. Those who cannot afford to build infrastructure at the households to cope with service intermittence may be in disadvantage compared to the better off. The impact on people's perceptions regarding this condition depends mainly on whether for people, water is a key asset to generate income or not.

Access to land and its ownership gives to people the opportunity to develop productive activities to ensure their livelihoods. However, many times, despite this activities are carried out they do not generate enough income to allow people a reasonable standard of living (Ruben & van der Berg, 2001; Pérez & Pérez, 2002). In *La Palma Tres Puertas* about 20% of households with water consumption less than 80 m^3/every two months, some of those engaged in farming, lived in poverty, earning less than 2US $ / day. None of the households with consumption over 80 m^3/every two months had these low income levels. This confirms that water is just one factor contributing to livelihoods, and that health, sanitation, education, agronomic knowledge, market linkages, veterinary services, and many other things are critical to improve people´s ability to escape from poverty (van Koppen, 2009)

La Palma Tres Puertas is a clear example of the transformation processes undergone by rural areas in Colombia, with the agricultural crisis, the increase in livestock, the change of permanent crops to pasture, and the inequality in land ownership. At the end, all these aspects are reflected in the pattern of water use within this rural water supply system, for example, in the significant amount of water that now is used for livestock, that before was probably dedicated to other purposes or not used.

Conclusions around objective 2: To measure different components of the domestic water per capita consumption in households within a MUS system

The household monitoring to determine the water per capita consumption for domestic uses resulted in a figure of per capita demand in a range from 44.3 to 95.6 lpcd with an average of 77 lpcd. The values obtained in the different households for each of the activities involved, were variable, indicating that this consumption is influenced by many factors such as, the number of taps, the system of sanitation, hygiene practices, people habits, preferences, etc. Activities with the highest consumption of water were bathing, washing dishes and laundry.

The obtained values of per capita consumption with this monitoring were lower than values reported by other studies conducted in rural communities in Colombia, and lower the range that the Colombian standard (RAS - 2000) allows for designing of rural water supply systems for domestic purposes 100-150 lpcd. However, within the water supply system, only 17% of households had exclusively domestic uses, while the remaining 83% developed productive activities that depend on water.

Conclusions around objective 3: To propose balances at the system and household level, including water demand for multiple uses and water availability, considering blue water and green water.

The possibility of using water balance concepts and budgets and their methodologies was tested at the scale of a MUS system under administrative boundaries, incorporating the concepts of green water and blue water. It showed the flexibility of these tools to suit the objectives of a study, scale, and availability of information. The water balance probed to be useful for understanding the dynamics of the hydrological cycle and the human cycle in a system, when the required and available information is collected, according to defined time and space boundaries, in order to obtain more reliable results.

The stratified analysis allowed estimating water consumption for domestic and productive uses, making clear differences between types of households within the water supply system, quantifying what was qualitatively described in first place. Thus, it confirmed that households in stratum 2 were highly dependent on rain, and despite the use of the water supply system for some productive purposes, a 55% of consumption was allocated to purely domestic uses. In contrast, in stratum 3 the water supply system was only used by 18% for domestic purposes and the remaining percentage for productive activities, like agriculture and animal husbandry.

Per capita domestic consumption varied few within the three strata in a range from 88 to 109 lpcd. In contrast, water per capita consumption for productive purposes, was 19 lpcd in stratum 1, 74 lpcd in stratum 2 and 413 lpcd in stratum 3. Therefore, based on the quantity consumed for productive uses in strata 1 and 2, it could be said those uses were "*minor, if not negligible" (v*an Koppen et al., 2009). However, the average quantity required for productive uses in stratum 3 was not negligible, and the chances of these consumption levels to be absorbed for a water supply system designed under the Colombian standard (100 – 150 lpcd), if everybody would have the same possibilities to use the water, would be difficult and may have impact on the system sustainability. However, the 183 lpcd required for domestic and productive uses by households in stratum 2 were slightly higher than the Colombian standard as well. Those results were particularly similar to the findings of Smits et al. (2010) in Honduras in a rural community, which productive activities were based on coffee production and animal husbandry as in *La Palma Tres Puertas*.

It was found that water consumption levels in this MUS system, depended not only on whether or not people developed productive activities and the scale, but also on the activities selected; being livestock, an activity with a significant weight on the demand for water in the system. Therefore, awareness about people´s livelihoods in an existing system providing water for MUS is required to find whether these uses can be carried out with the amount of water and the infrastructure available, and how to introduce these realities in the operational rules and system management.

Sustainable Livelihoods, Demand Responsive, and therefore Multiples Uses approaches need to be incorporated into planning in Colombia, including the water needs of the people and the available supply. The current design standard, besides being insufficient for uses in rural areas, promotes inequality between urban and rural areas (allocations are higher for the cities). However, adopting these approaches implies the need for different strategies for training water professionals and certainly, involves a cost in the planning phase derived from the need for additional activities such as surveys, to collect information that currently is not used. Though, this cost may be lower compared to the benefit of anticipate real future demands on the system and work towards sustainability. The costs of the infrastructure with higher capacity should also be considered in the analysis.

Appropriateness of the methodologies used

Although, there was already information on multiple uses in *La Palma Tres Puertas*, this study posed new questions and adopted strategies based on the existing information to go slightly further to find out on the influence of aspects of poverty and livelihoods on the levels of water consumption the area. The possibility to cross information about livelihoods and poverty with records from water meters, allowed enriching the analysis.

The household survey was an appropriate method to collect information related to issues of poverty, livelihoods and access to water, especially in this community where homes were scattered and there was low participation of local people in community activities, which had impeded the implementation of other strategies, such as focus groups. However, given the inconsistencies in some responses relating to income levels by some users, and the fact that this seems to be a sensitive issue, it is important to try to get this information using a combination of different strategies.

Achieve people participation in the household monitoring of domestic water use was not an easy task due to the distrust of many people on the purposes of the research. This limited the monitoring only to 6 homes. Additionally, the methodology originally proposed had to be modified, which meant the change of direct observation by the author to filling out water diaries by people in households and restrict the activity to record domestic consumption, since who agreed to fill the diaries were housewives. The validity of the results would be improved, with participation from a greater number of households.

Despite the limitations on the household monitoring, the methods provided an idea of the water consumption levels for different activities and an estimate of total domestic per capita demand. However, those methods were subjected to a variety of "social desirability bias" (Posdakoff et al., 2003), since participants may have changed their behaviour, i.e. adopt more rational water consumption or more stringent hygiene practices; the water diaries also may have lead to under-report some uses that were not developed directly by the person in charge to keep the records. In addition, the fact that taps were measured just once, also introduced an error. Although, these sources of bias and errors may be reduced by applying the principle of triangulation, as in this case, using records from the meters and information from the household survey.

In particular, the stratified sampling strategy allowed to identify, how and why within a system in which potentially all have the same level of service, some benefited more than others with it. Although, the precision achieved was lower to draw conclusions for stratum 3, since it was not possible to obtain the desired sample size. However, it provided a clearer picture of this group of households, which was not visible enough in previous studies (Cinara, 2006, Ospina, 2009). Even though, these households are not the targeted beneficiaries of MUS, its recognition is important because, the impact of a small number of them can compromise the service sustainability for the majority.

Combining information from meter records with surveys and monitoring use of water, contributed to improve the reliability of the results and to minimize bias. This approach is not documented in previous studies of MUS. To do this, it was fundamental to study the methodologies implemented by other researchers on water topics from other perspectives. The approach to study the availability of water was also different, since, in most previous studies of MUS, it was generally based on people perceptions. The approach here was to take into account the hydrological cycle, and to introduce the concepts of green water and blue water in the analysis. However, the obtained figures are indicative, since their estimation were based on several assumptions and rough information. Therefore, it is required to improve not only the type of information that should be elicited through surveys, but also to have more reliable reference values for the consumption factors used for the estimates.

Recommendations for future research

Recommendations for future research are summarized below

- Study water productivity for the area
- Study the variation of per capita demand for domestic and productive activities for wet season and compare to the results obtained in this study for the dry season
- Study on how these families ensure their food security and whether both the water supply system and rainwater, have capacity to allow people having gardens looking for self-sufficiency, or less dependency on the market for their food needs, especially in the case of the poorest families
- Study from the technical perspective, the effect that household storage tanks have on the system performance to establish if their presence is related to the service intermittence
- Explore alternatives to improve the use of rainfall in the area as a strategy to increase agricultural yields
- Investigate whether the differential price of the tariff, includes the costs of providing the service, and reflects principles of equity, solidarity and efficiency, given the differences between users discussed, and the need to make rational use of the resource, since the water supply system operates at full capacity and using water from a sub-basin transfer.
- Research water consumption reference values for local species of livestock and typical crops, whose water needs are not available in the published literature

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APPENDIX

Appendix A Household Survey Questionnaire

SURVEY ON MULTIPLE USES OF WATER IN THE VILLAGES OF LA PALMA AND TRES PUERTAS (RESTREPO)

Good morning, Cinara Institute of Universidad del Valle is studying about water issues in *La Palma Tres Puertas* water system since 2005. Today, we would like to ask you some questions for our research. Participation is voluntary and the information obtained is confidential. Neither Cinara, the Water Committee nor other institution will be able to know your answers to the different questions. Nevertheless, your answers will help us to understand what is required to improve the design and the administration of rural water supply systems.

Date ___ / ___ / 2010 Interviewer _____________ Settlement_____________________

A. GENERALITIES OF THE CUSTOMER AND THE HOUSE

A.1. Respondent´s name: __________________ A.2. Customer´s name: __________________________

A.3. How long have you been living in Palma Tres Puertas? Years___ Months___

A.4. Are you the household head?

01	YES ***(go to question A.6)***
02	NO

A.5. What is your relation with the household head?

01	Husband/Wife
02	Father/Mother
03	Son/Daughter
04	Brother/Sister
05	Other relative, Which? ____________
99	Does not apply

A.6. Gender of the respondent:

01	Masculine
02	Feminine

A8. Are you working currently?

01	YES
02	NO ***(go to A10)***
99	Does not apply

A.9. What is your current occupation?

01	Day laborer
02	Farmer
03	Public employee (professor, work at the town hall, in a pubic office, with the police force)
04	Employee (Work in a farm, company, office, deprived business, etc)
05	Independent worker (electrician, plumber, mechanic, welder, etc)
06	Informal worker (itinerant sales, various activities according to opportunities, etc)
07	Merchant (store, restaurant, coffee shop)
08	Other ____ Which? _________________

A10. In case, the respondent is not the household head. What is the household head occupation?

01	Day laborer
02	Farmer
03	Public employee (professor, work at the town hall, in a pubic office, with the police force)
04	Employee (Work in a farm, company, office, deprived business, etc)
05	Independent worker (electrician, plumber, mechanic, welder, etc)
06	Informal worker (itinerant sales, various activities according to opportunities, etc)
07	Merchant (store, restaurant, coffee shop)
08	Other ____ Which? _________________

A11. The house in which this family lives is:

01	Own
02	Rented
03	Familiar
04	Borrowed
99	Does not apply

A12. Total of people living in this house: _________

A.13. What is the total area of the homestead? _________ Ha ____ m^2 ___ Other ___

B. WATER AND LAND USE

B.1. What is the water source used for each of the following domestic tasks?

Domestic tasks	Water source used					
	Water supply system	Rainwater	Well	Stream	Other	N. A.
B.1.1. Personal hygiene						
B.1.2. Cooking and drinking						
B.1.4. Cleaning of the house						
B.1.5. Washing clothes						
B.1.6. Irrigation of garden						

B.2. What´s the household system to eliminate excreta?

01	Open defecation	03	Pour flush latrine	05	Discharge to natural drainage
02	Latrine	04	Toilet + Septic tank	06	Other __ Which?_____________

B.3. Please indicate the following aspects regarding animal husbandry and water

Type	a. Presence		b. Quantity	c. Occupied area (Ha, m2)	d. Water source used for drinking and cleaning					
	Yes	No			Water supply system	Rainwater	Well	Stream	Other	N.A.
B.3.1. Pigs										
B.3.2. Chicken										
B.3.3. Cows										
B.3.4. Horses										
B.3.5. Other										

B.4. Please indicate the following aspects regarding crops and water

Type	a. Presence		b. Occupied area. (Ha, m2)	c. Irrigation is required?		d. Frequency of irrigation/ Time	e. Months of the year	f. Irrigation method [a]	g. Water source used for irrigation[b]
	Yes	No		Yes	No				
B.4.1. Coffee									
B.4.2. Pineapple									
B.4.3. Bean									
B.4.4. Maize									
B.4.5. Veg.									
B.4.6. Other __________									

b 1. Drip irrigation 2. Sprinklers 3. "Mateo" 4. Back pump 5. Furrow 6. Other 99. Do not apply
a 1. Water supply system 2. Rainwater 3. Well 4. Stream 5. Other 99. Do not apply

C. PERCEPTION OF THE SERVICE OF WATER SUPPLY

C1. What is your opinion about the water service in terms of quality and quantity?(Select one or several of the answers)

01	Bad quality
02	Few quantity
03	Does not have any problem
88	Does not know the condition of water
99	Does not apply

C.2 How many days per week do you receive the water service?

01	One	05	Five
02	Two	06	Six
03	Three	07	Seven
04	Four	88	Do not know

C.3. Do you have storage tank or some other container to store water? Yes __ No __ (go to C.8.)

C.4. What is the total storage capacity of the household?_________ ____m^3 ___ gal ___ L

C.5. How affected do you feel because of the water intermittence?

01	Highly
02	Moderately
03	Few

C.6. How important do you think is a good water service for the economic development of the region?

01	Important
02	Moderately important
03	Not so important
04	Does not know if the problem exist
99	Does not apply

D. FAMILY INCOME

D.1. How many people in this house work?___________

D.2. Which is the value of the average household expenses?_________$/week, ___ $/month ___ Other, which? ______

D.3. In which of the following ranks the average monthly household income is?

01	Less than COL$260.000
02	COL $260.000 - COL $515.000
03	COL $515.001 - COL $650.000
04	COL $650.001 - COL $867.000
05	COL $867.001 - COL $1.084.000
07	More than COL $1.084.000
08	Does not know

E. WILLINGNES TO PAY

The Universidad del Valle has studied since 2002 how rural families use water and how this use differs from the one of urban families. In spite of the differences, laws and norms for designing and managing water supply systems are the same for rural and urban areas.

For rural families, basic consumption should include human consumption and water demand to cultivate small plots and raise animals like poultry, pigs or cows, from which families obtain their income. Nevertheless, investments of the government are oriented to construction of water systems exclusively for domestic purposes.

The lack of recognition of these uses is reflected in the design, management and operation of water systems. This situation limits people to access to water and makes more difficult to assure the food security and income required for the improvement of quality of life.

E1. Would you agree that norms of water supply systems allow the use of water for activities like animal husbandry and small scale irrigation?

01	YES
02	NO
99	Does not apply

Intermittence on service provision also make more difficult to use water for animal husbandry and crops. In the hypothetic case where the government undertakes some investments to improve the service continuity but it would imply an increase of the tariff from the actual COL$5000 for 25 m^3 and 300 additional m^3 and considering your household income and expenses **(note: It is important to highlight on the fact that this is HYPOTHETICAL),**:

E2. Would you agree to pay a monthly tariff of COL***$7000 for 25 m³*** to improve the continuity of the water service and therefore, to be able to use water for animals and crops without having conflicts with the Water Committee?

01	YES
02	NO
99	Does not apply

E3. Considering the monthly tariff, what is the maximum monthly value that you would be willing to pay for an improvement of the service?_____________for the 25 m^3 ***(If the respondent says that he/she is not willing to pay any value, go to E4; if he/she answers a value, go to E5).***

E4. Why you are not willing to pay any value for an improvement of the service?

01	Does not have enough money to pay
02	The municipal government must pay for this type of service
03	Is not interested in water
04	Would prefer to pay to solve another problems
05	Does not believe that the improvement can be done
06	Is satisfied with the service
07	Other. Which?
99	Does not apply

E5. Why you are willing to pay this maximum value (please read to the respondent the following options)?

01	Has enough money to pay
02	Is interested with in water
03	The water problem is critical for the locality
04	Thinks that water is fundamental to undertake his work
05	Other. Which?
99	Does not apply

E.6. Observations
____
____

F. WILLINGNESS TO PARTICIPATE ON AN ADDITIONAL STUDY

F.1. Would you willing to participate in an activity to investigate the use of water in your home for one day? Those activities would be exclusively for investigation purposes, and information obtained would be confidential.

Would you feel disposed to participate? Yes ___ No ____.

THANKS A LOT FOR YOUR TIME!

Appendix B Processed information from Water Diaries

- Processed information on domestic water consumption obtained from the six households monitored is included in an Excel file labelled “Appendix B”, contained in the CD that accompanies this document

Appendix C Water Balance Spreadsheet

- Water balance for all households within the sample is included in an Excel file labelled “Appendix C” contained in the CD that accompanies this document