PARTICIPATORY MODELLING FOR HOLISTIC UNDERSTANDING OF CATCHTMENT HEALTH AND HUMAN HEALTH IN ANDEAN RURAL MICROCATCHMENTS, THE CASE OF CALABAZAS

By

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September 2014

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Abstract

In rural catchments of developing countries, land use change, inadequate access to education, health care, water and sanitation, and lack of institutional support are common problems which affect poor people. Integrated Water Resource Management (IWRM) which advocates for the coordinated management of water, land and related resources, and EcoHealth which holds that human health and wellbeing are outcomes of effective ecosystem management, promote catchments as tangible contexts to fulfil overlapping objectives across fields. This research links IWRM and EcoHealth using System Dynamics (SD) as a tool to increase the level of shared understanding of the socioeconomic and environmental factors influencing environmental health and human health and wellbeing in an Andean rural microcatchment in Colombia.

Stakeholders´ knowledge was elicited through semi-structured interviews and documents. A Causal Loop Diagram was prepared to organize this knowledge and to identify the model structure. Information on socioeconomic and environmental variables was collected through three surveys: i) household; ii) stream water, and iii) drinking water. The household survey captured relevant social determinants of health. The stream water survey investigated stream health in relation to point and non-point pollution sources. The drinking water survey identified risks to water quality. Using SD principles and the Stella software, a series of focus groups enabled stakeholders to develop a semi-quantitative model.

The resultant model comprised six interrelated sectors: population, economic, land use, stream health, human health, and management. The modelling process increased stakeholders´ understanding of their system, and helped them to identify interactions of distal and proximal factors to produce outcomes on catchment and human health. The model was a strategy for integration and a communication tool. The process allowed the incorporation of knowledge, concerns and perceptions from the different actors, disciplines, institutions and sectors involved. The process facilitated identification of limitations and benefits of existing policies and the need for policies to address neglected problems. The research contributed to methodology development in the field of IWRM – EcoHealth, testing System Dynamics Modelling as a strategy to elucidate complex social, economic and environmental linkages at the catchment scale that could be applicable to similar rural mountainous contexts.

Acknowledgements

I would like to express my deep gratitude to:

John Gowing, Charlotte Paterson and Inés Restrepo, my supervisors, who have encouraged me and provided valuable guidance along this process. In particular, Mr Gowing, who beyond the production of a thesis, cared about my wellbeing; and to Inés, who has been my mentor, colleague and friend for many years.

To all my stakeholders, coffee farmers, ranchers, government officials, and staff from NGOs. Especially to those at the Departmental Coffee Committee of Valle del Cauca: Jorge, Rocio, Asmed, Claudia, Stephaney, Olga, Wilson, Juan Carlos, Sandra, and Camilo. I make a special mention to Patricia who was my guide and taught me how to move in *Calabazas*. Above all, to Dr Ospina, whose openness and vision, made this collaborative research possible.

To the people from *Calabazas,* kind and generous, who provided important information to develop this work. Especially to those who cooperated in a responsible and committed manner on data gathering, and through the process shared their knowledge and experiences: Alfonso, Antonio, Elizabeth, Estella, Euciber, Flover, James, Martha, Obed, Parmenides, and Susana. To Carlos Julio, who was my driver in the hills of *Calabazas*.

To the people from the different institutions who contributed with their knowledge to enrich this research: Diego Rivera, Andrés Sinisterra, Julián Chará, Luis Isaza, Luis Marmolejo, Janeth Sanabria, Julián Isaza, Andrés Echeverry, Javier Holguín, Eduardo Medina, Andrés Carmona, Rodrigo Sánchez, and many others.

To my friends and colleagues: César Vivas who helped me with GIS data; Jaime Jiménez, who shared with me his wisdom in the intricacies of monitoring Andean sources and accompanied me in the collection of samples in *Calabazas* stream. To Isabel Bolaños and Clara Roa who taught me to use the DelAgua kit, and to Paola Chaves, notekeeper during focus groups meetings. My special thanks to Wilmar Torres who provided me assistance on statistical analysis with the R software.

To the Administrative Department of Science, Technology and Innovation of Colombia (COLCIENCIAS) who sponsored my PhD studies, and to the International Foundation for Science (IFS) who provided funds to conduct my field activities. To Cinara and its administrative staff, John Bolaños and Sandra Cardenas, who managed IFS funds. Also to those in the Laboratory, Clara González and Noel Muñoz. In addition, to Dany Acevedo from EIDENAR Laboratory.

To my friends Lisa, Tounis, Huda, and Wi, who made more enjoyable my time in Newcastle. Lisa was especially supportive in the most stressful times at the end of this process.

To my father, my mother and my sister for their support, for teaching by example and being a source of inspiration to me. To Alejandro because he left me the most important lessons for life. To my mum and aunties that were adorable assistants in some field tasks. To my mum in particular, whose words provide me with confidence to face new challenges. To all the members of my family, each of whom I am grateful to have in my life.

To Ricardo, my husband, for his incommensurable support and trust. I feel deeply blessed for the team we are.

Gracias a Dios… y *gracias a la vida que me ha dado tanto*…

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

List of Appendices

Acronyms and Abbreviations

A	Assumed after considering literature sources, discussion with stakeholders through individual meetings, or both
Acuavalle	Society of water and sewage for Valle del Cauca
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
C	Converter
CAS	Complex Adaptive Systems
CC	Coffee Contribution
Cenicafe	Coffee Research Centre
CFU	Colony Forming Units
CIF	Forestry Incentive Certificate
CIPAV	Centre for research on sustainable agricultural production systems
CLD	Causal Loop Diagram
Cogancevalle	Cooperative of livestock farmers of Valle del Cauca
COD	Chemical Oxygen Demand
COP	Colombian Peso
CPI	Collection of primary information
CSDH	Commission on Social Determinants of Health
CSI	Collection of secondary information
CVC	Environmental Authority for Valle del Cauca Department
DANE	National Department of Statistics of Colombia
DCC	Departmental Committee of Coffee Growers from Valle del Cauca
DO	Dissolved Oxygen
DP	Dual Purpose livestock farming
DPSEEA	Drivers-Pressure-State-Exposure-Effect-Action
E	Estimated
E. coli	*Escherichia coli*
EcoHealth	Ecosystem Health
Fedegan	Colombian Federation of Livestock farmers
F	Flow
FoNC	National Coffee Fund
FRGS	First Round Group Semi-structured interviews
GIS	Geographical Information System

GDP	Gross Domestic Product
GMB	Group Model Building
GPS	Global Positioning System
Ha	Hectare
HDR	Human Development Report
HWT	Household Water Treatment
IWRM	Integrated Water Resource Management
kg	Kilogram
l/s	Litres per second
LAC	Latin America and the Caribbean
mg/l	milligrams per litre
Me	Median
MDGs	Millennium Development Goals
MM	Mediated Modelling
MPN	Most Probable Number
N.A.	Not Applicable
NFC	National Federation of Coffee Growers of Colombia
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
PES	Payment for Environmental Services
PFP	Peace Footprints Project
QMRA	Quantitative Microbial Risk Assessment
RADWQ	Rapid Assessment of Drinking-Water Quality
S	Stock
Sd	Standard deviation
SD	System Dynamics
SENA	National Learning Service
SES	Socio-ecological system
SU	Sanitation Unit
TTC	Thermotolerant Coliforms
TSS	Total Suspended Solids
USD	United States Dollar
WFD	Water Framework Directive
WHO	World Health Organization
WSS	Water Supply Systems

Chapter 1. Introduction

1.1 Context

In rural areas of developing countries, agriculture intensification, trying to meet the increasing world food demand has led to significant environmental impacts including: deforestation, and intensive water resource use and degradation, that in turn have effects over human health. Deforestation causes alteration and loss of ecosystem services (Gomiero *et al*., 2011), and in poor and tropical communities could facilitate the interaction between pathogens, vectors and hosts, increasing disease rates (Patz et al., 2004). Higher use of water to meet growing agriculture and livestock demands reduces availability for other purposes (Gomiero *et al*., 2011), raising the vulnerability to diseases associated with poor hygiene (Patz *et al*., 2004). Furthermore, agriculture and livestock generate water pollution that represents threats to human health. In particular, livestock intensification produces runoff from rangelands with significant loads of pathogens that can pollute water sources used for human consumption (Patz *et al*., 2004).

Microbial pollution represents a serious concern in rural areas of developing countries. Besides runoff from rangelands, discharges from individual and collective sanitation systems, generally without treatment, are also pathogen sources. Individually, these pollution sources may be minimal, but collectively they can have significant adverse impacts (Keirle and Hayes, 2007). These characteristics pose unique challenges for rural catchments, since they contain both point and non-point sources of microbial pollution and at the same time, they are providers of ecological services, including good water quality and quantity for multiple uses (Harden, 2006; Sinclair *et al.*, 2009; Villamarín *et al.*, 2013). Microbial pollution of surface waters represents a barrier and a risk to uses like drinking water for humans and livestock, irrigation and recreation (Traister and Anisfeld, 2006).

Access to drinking water polluted by pathogens, lack of safe systems for handling excreta and poor hygiene are major causes of diarrhoea (Bartram and Cairncross, 2010; Casellas *et al.*, 2012). Worldwide, diarrhoea and subsequent malnutrition are the main causes of infant mortality (Bartram and Cairncross, 2010; Black *et al.*, 2010), estimated at about 2.5 million deaths and four billion cases each year (Bbaale, 2011; Casellas *et* *al.*, 2012). However, it is believed the figures are higher due to underreporting, the ubiquity and the multifactorial nature of the hazard (Khan *et al.*, 2007). Even though, in the last decades, diarrhoea mortality has markedly reduced, morbidity remains a problem (Ferrer *et al.*, 2008; Sartorius *et al.*, 2010; Markovitz *et al.*, 2012), and rural communities in developing countries, those with lower levels of access to improved water and sanitation (WHO/UNICEF, 2013a), are highly vulnerable.

Water quality must be protected not only to ensure human health. A management approach to water protection is recognized as a strategy to address the anthropogenic changes to watersheds that degrade water quality, reduce ecosystem services, and threat human health (Confalonieri and Schuster-Wallace, 2011; Casellas *et al.*, 2012). In particular, microbial diffuse pollution require an approach to catchment management (Keirle and Hayes, 2007), and even at sub-catchments or homestead level, due to the spatial and temporal complexity of pathogens (Winter *et al.*, 2011). Furthermore, in the developing world, water is also a key element to promote sustainable livelihoods in rural communities that depend on agricultural production (Merrey *et al.*, 2005; Bunch *et al.*, 2011). Despite the fact that poor rural areas have multiple and interrelated needs, institutions tend to implement single-dimension development proposals (Merrey *et al.*, 2005). Nevertheless, at least conceptually, these trends are progressively changing with the emergence of paradigms that seek to address environmental degradation, human health and wellbeing through integrative approaches (Corvalán *et al.*, 1999; Ezzati *et al.*, 2005; Batterman *et al.*, 2009; Parkes *et al.*, 2010; Bunch *et al.*, 2011; Confalonieri and Schuster-Wallace, 2011; Charron, 2012).

Integrated Water Resources Management (IWRM) and EcoHealth are examples of more holistic approaches to natural resource management, human health and wellbeing. IWRM holds that land-based human activities and natural events within catchments, influence the availability and quality of water resources (GWP-TAC, 2000; Nakamura, 2003). Under IWRM, the catchment is the managerial unit throughout which all decisions and actions have interdependent ecological, social and economic implications (Everard, 2004). In EcoHealth, human health and wellbeing are seen as dependent on ecosystems and outcomes of ecosystem management (Rapport, 2007). This approach is used to better understand the connections between nature, society, and health, and how drivers of social and ecosystem changes influence human health and wellbeing (Wilcox and Kueffer, 2008). Recently, the integration of IWRM and EcoHealth has been proposed to address "overlapping objectives" across human health and environmental management, using the catchment as the "ideal analysis unit". It is believed this integration will allow addressing synergistically water quality, quantity, ecosystem services, social determinants of human health and wellbeing, health promotion, natural resource management and poverty reduction (Parkes *et al.*, 2010; Bunch *et al.*, 2011). It is being proposed this integration can be beneficial to address water related diseases, and to enhance sustainable livelihoods in agricultural economies (Bunch *et al.*, 2011).

Several conceptual frameworks have been proposed to incorporate holistic and integrative approaches to address the connections between environment and human health, including: the Drivers-Pressure-State-Exposure-Effect-Action (DPSEEA) (Kjellstrom and Corvalan, 1995; Corvalán *et al.*, 1999), The Environmental Determinants of Infectious Disease (EnvID) (Eisenberg *et al.*, 2007), the Multidisciplinary health-based system (Batterman *et al.*, 2009), and the Watershed governance prism (Parkes *et al.*, 2010). In the watershed governance prism proposed within IWRM-EcoHealth, vertices represent: i) ecosystems, ii) social systems, iii) health and wellbeing, and iv) watersheds. The authors suggest a stepwise approach in which important characteristics in all four vertices are examined for a particular watershed. They suggest investigation using the prism axes helps to identify relationships, priorities and concerns, but recognize this approach suggests linear connections.

A common feature among the claims of authors interested in environment health-human health connections is the recognition of the relevance of a systemic perspective to facilitate understanding of the complex relationships between elements of diverse nature (Eisenberg *et al.*, 2007; Batterman *et al.*, 2009; Parkes *et al.*, 2010; Bunch *et al.*, 2011; Eisenberg *et al.*, 2012). Systems thinking is a transdisciplinary field, which provides a specialized language and tools that help to understand complex problems (Sterman, 1994). System Dynamics (SD) is one branch within the systems thinking approach that uses qualitative and quantitative modelling tools to reveal and understand system´s behaviour, communicate with others about this understanding, and design high-leverage interventions (Hjorth and Bagheri, 2006; Richardson, 2011; Mirchi *et al.*, 2012). This research develops a participatory process, using SD principles and tools, to elucidate the complex relationships between socioeconomic and environmental factors that influence human health and wellbeing in a rural Andean microcatchment in Colombia, testing the premises of the IWRM-EcoHealth approach.

1.2 Research aim and objectives

This research is an empirical application of the premises from the IWRM-EcoHealth approach. The aim of this research is to contribute to the field of IWRM-EcoHealth to increase the understanding on the linkages between socioeconomic and environmental determinants of human health and wellbeing and natural resources management at the catchment level, testing System Dynamics as a methodology that helps to elucidate the connections between factors from different dimensions at different scales, proximal and distal, involving multiple perspectives, disciplines, and integrating qualitative and quantitative data collection and analysis strategies.

The research objectives are:

- To understand stakeholders´ perceptions of the micro and macro factors affecting catchment health and human health and wellbeing

- To analyse evidence on the behaviour of micro and macro socioeconomic and environmental factors related to catchment health and human health and wellbeing

- To develop a participatory systemic model that contributes to improve understanding of the relationships between micro and macro socioeconomic and environmental factors over catchment health and human health and wellbeing

The investigation followed the case study research tradition, adequate to deal with complex, multi-scale, and multi-layered systems, involving knowledge from several disciplines, integration of qualitative and quantitative research methods, and connect real-world problems with scientific theory building (Scholz *et al.*, 2006). The case study tradition is appropriate where the researcher has no control over behavioural events and the investigation is focused on contemporary issues (Yin, 2014).

The place selected for the case study was *Calabazas* microcatchment, located in the Andean region in Colombia. *Calabazas* was selected for being the place where a national Non-Governmental Organization undertook a development project framed in the context of a pilot for IWRM implementation. The organization was simultaneously addressing interventions on natural resources conservation and farmer´s wellbeing.

While *Calabazas* is a typical microcatchment of the Colombian Andes where coffee is grown, the context of the intervention was unique, as in Colombia, development interventions are generally implemented by single-mandate institutions, at different time scales, and under political not hydrological boundaries. A background to the case study is described below.

1.3 Background to the case study

Colombia is located in the north-western part of South America (Figure 1-1). The country occupies 1,141,748 km^2 and has a total population estimated around 47.6 million inhabitants (DANE, 2014c). While the rural population has declined in percentage terms from 60% to 24% in the last 60 years, it is still significant, about 11.7 million (World-Bank, 2014). Furthermore, around 76% of the urban municipalities have predominantly rural characteristics, which in practical terms mean rural population could reach about 15 million people (PNUD, 2011). The country is geographically divided in 5 main regions with strong different characteristics and the population is unevenly distributed in those regions. The Andean region is the most highly populated, concentrating 74% of the inhabitants in 8% of the country area (Meisel, 2007).

Colombia is classified as an upper middle-income country; petroleum, coffee, coal, emeralds, flowers and bananas being the main exports. The estimated Gross Domestic Product (GDP) at Purchasing Power Parity for 2012 was 11,892 international dollars per capita (World-Bank, 2014). Inequality is one of the highest in Latin America, the Gini coefficient is 0.54 (DANE, 2014d). Poverty and inequality are some of the country's main challenges (World-Bank, 2010), and in rural areas poverty is higher compared to urban areas. While in 2013, the multidimensional poverty index for urban areas was 24.8, in rural areas it was 45.9 (DANE, 2014d).

Agriculture is a central activity within the economy, although, its GDP decreased from 25% in 1970 (Gutiérrez, 2009) to 7% in 2013 (World-Bank, 2014). Despite this situation, agriculture and livestock are the main rural livelihoods. 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 countryside have led to an unequal distribution of land, where 1.15% of the population owns 52% (PNUD, 2011). Many large farms are dedicated to extensive livestock (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).

Figure 1-1 Colombia and its location

Google-earth (2014)

Along with the unequal distribution of land and income, access to water and sanitation services is uneven in the rural areas compared to the urban areas. Colombia has a decentralization model of public service provision, allowing private sector participation. The private sector operates especially in cities (Foster, 2005), while in the rural areas the service is provided by local communal organizations, that frequently present weak operational and financial indicators, and supply water of deficient quality (Dominguez, 2010; Smits *et al.*, 2013). Access to improved water is 100% in urban areas, while in rural areas it is 72%, lower compared to rural areas of LAC (81%) (WHO/UNICEF, 2013a). These figures do not include quality and continuity, thus, the actual coverage is thought to be lower (Rojas, 2008). Access to improved sanitation in rural areas is 65%, slightly higher than for rural LAC (61%), and lower than for the urban Colombia (82%) (WHO/UNICEF, 2013a).

Approximately, 33% of the country's area is mountainous, with mainly tropical climate and uniform temperatures, with some differences according to altitude. The geographical location, varied topography and climate regime characterize Colombia as one of the territories with major water availability in the world (2,265 Km^3/year). However, this availability is temporally and spatially heterogeneous; some areas suffer deficits, specially where most population is concentrated and water yields present low values, such in the Andes (IDEAM, 2010a). In this region, the large population commonly obtains water from small streams, creeks, and rivers; generating high pressure on these catchments. Furthermore, headwater streams have highly modified flows due to water abstraction and the alteration of the water regulation capacity of soils (Roa-García *et al*., 2011) .

Together with the unequal access to water and sanitation, and the spatial variability of water availability, pollution is another challenging area. According to Vidal *et al.* (2009) *"the main watersheds are heavily polluted as result of deforestation, dumping of domestic and industrial wastewater without treatment, agricultural runoff and discharge of solid waste, leachate, among others".* This situation poses health risks for the population, especially children. In the country, diarrhoea is the fourth cause of mortality in children under 5 years old (OMS, 2010).

The Colombian Andes also comprises the coffee region, which covers 3.3 million Ha, from which 914,000 Ha are coffee plantations (FNC, 2011), interwoven with subsistence crops, pasture, and forest remnants (Etter *et al*., 2006). Despite the fact that since the 1990, coffee has lost importance in terms of its contribution to the GDP (Forero Álvarez, 2010), it remains the livelihood of 560,000 families, and generates 631,000 jobs per year, surpassing any other agricultural sector (Cano *et al.*, 2012). Therefore, the viability of coffee production is seen not solely a matter of coffee growers, but of national interest (Elespectador, 2012).

National Federation of Coffee Growers

Colombian coffee growers are unionized through the National Federation of Coffee Growers (NFC). NFC is a farmers organization, established in 1927, looking for the wellbeing of Colombian coffee growers and their families. NFC is a non-profit, guild organization, whose members are elected from the same coffee producers, and is considered one of the largest rural NGOs in the world, with presence in all rural areas where coffee is grown in Colombia. The NFC has the National Coffee Fund (FoNC) since 1940. The FoNC is a para-fiscal levy that feeds from coffee farmers´ contributions. FoNC's resources are used to provide the "social goods of coffee growing": i) purchase warrant, ii) scientific research, iii) technology transfer, iv) marketing, and v) management and implementation of social programs (FNC, 2010).

Despite these achievements, the Colombian coffee sector is in crisis since the 1980s. In particular, the guild has been unable to overcome the break of the Odds Pact in 1989 (Cano *et al.*, 2012). This situation lead Colombian coffee farming exposed to free market and represented dramatic changes for the coffee institutions (Murillo, 2010). In the 1990s, the NFC sold several of their assets, and recently it has been strongly criticized on the management of inventories, price to producers, and the institutional structure (Suárez, 2005; Robledo, 2007). In addition, the FoNC´s resources have diminished dramatically. However, the NFC is still successful leveraging resources from national and local governments, clients, multilateral banks and international institutions to advance development strategies in Colombian rural areas (FNC, 2010). Despite the coffee crisis and the criticism to the NFC, it is recognized the wellbeing of millions of rural people in Colombia depends on the NFC maintains its leadership and cohesion (Elespectador, 2012). Even its critics recognize its crucial role to protect poor smallholder farmers of a market driven by powerful foreign multinational companies (Colprensa, 2012).

The NFC developed the strategy “sustainability in action” with interventions around: coffee farm, community, environment and connectivity (FNC, 2010). In addition, as part of the strategies to adapt to the business challenges, Cenicafe, the NFC research institute, formulated in 2011 a proposal that conceptualizes their approach towards IWRM, that articulates efforts on: i) development of high yielding coffee varieties to increase crop production and reduce the demand for agrochemicals; ii) monitoring climatic variables, through a network of stations; iii) climatic zoning of the coffee region; iv) soil conservation; and v) efficient water management and anaerobic treatment of coffee processing wastewater, among others (Cenicafé, 2011).

Action research initiative

The Departmental Committee of Coffee Growers of Valle del Cauca (DCC), which is the sectional for Valle del Cauca department of the NFC in Colombia, is a pilot case for implementing IWRM. In the structure of the departmental committees at NFC, farmers are served in administrative units called districts. Across the country, districts matched political boundaries. In Valle del Cauca, districts were microcatchments, where staff, budget, information systems and projects were developed using this managerial unit.

By incorporating IWRM, DCC embarked on several projects to develop the approach, among them, "Sustainability of communities in healthy microcatchments". This project, known as Peace Footprints (PFP), was funded by international cooperation, for 5 years starting in 2011. PFP was selected as part of the context to conduct this research. PFP aim is to "*improve the living conditions of rural communities in Valle del Cauca, working around water as the guiding principle in pursuing poverty alleviation and sustainable development, creating favourable environment for life, work and the production of goods and services"*. The project had six components involving water, sanitation, food security, forest protection, capacity building and coffee competitiveness (Cafeteros-Valle, 2010).

The reasons for which DCC and PFP were seen as an appropriate context to develop this doctoral investigation were: i) interests from DCC; ii) student's interest in cross-cutting issues to rural development and water; and iii) identification of a need to develop knowledge, tools and methodologies for implementers. The research proposal was elaborated from conversations with DCC staff, and was framed according to the context, the stakeholder needs, the student´s interests, and the opportunities and challenges envisaged.

DCC implemented PFP in three microcatchments in its area of influence that includes the microcatchments of the Cauca River in Valle del Cauca department, where coffee is grown. In this department, *Cauca* river basin has 34 subcatchments, and 182 microcatchments, 162 having coffee. DCC selection of the three microcatchments was based on: catchment area, proportion of coffee to the catchment area, number of coffee farms, and community acceptance of the project. For the PhD research, *Calabazas* was selected among the three for having less security issues and easier access.

1.4 The case study area: *Calabazas* microcatchment

Calabazas is located in *Valle del Cauca* department, and drains to the Cauca River by its left bank, through the *Piedras* subcatchment. It is located at 4 ˚ 05 'North Latitude and 76 ˚ 37' West Longitude, in the western Andean range, and its total area (14 Km^2) belongs to *Riofrío* municipality. Nearby municipalities are *Tuluá, Yotoco* and *Calima*. The microcatchment includes territories that are part of *Fenicia* and *Portugal de Piedras* districts, comprising portions of the villages: *Calabazas, San José de la Selva, Miravalle, El Bosque, Puerto Arturo, Puerto Fenicia* and *Santa Rita*.

Calabazas has a range of altitudes between 1000 and 1900 m. The climate presents a bimodal behaviour with two rainy (April-June and October-November) and two dry seasons (January-March and July-August). The annual balance between precipitation (1636 mm/year) and evaporation (1248 mm/year) is positive, and the average annual temperature is 22°C (CVC, 2009).

The microcatchment is located in the Andean forest ecosystem, specifically in the humid premontane forest (CVC, 2012). *Calabazas* can be divided in three areas: i) from 1000 to 1300 m, piedmont zone, covered by pasture and stubble, and used for livestock farming; ii) the coffee region, from 1300 to 1800 m, located in a succession of high hills; and iii) from 1800 to 1900, the steep area where natural forest predominates. Coffee and livestock accounted for most of the area, while commercial forest, remnants of natural forest and scattered houses occupied the remaining land.

The microcatchment drainage system is torrential, for which it is required to preserve riparian vegetation to control flows (Loaiza, 1995). However, in the lower part, this vegetation disappeared. Reports from several institutions agreed on the fact that in the region water sources were subject to pollution from the headwaters to the outlet due to untreated domestic and coffee processing wastewater, agrochemicals and runoff from rangelands (CVC, 1977; Loaiza, 1995; Riofrío, 2001; Riofrio, 2012). However, there were no reports on water quality of the sources.

The economy was dependent on the agricultural and livestock sectors. Farm production was mostly coffee associated with plantain and banana, and animal husbandry including poultry, and small units of pigs and cows. There were a small proportion of farms exclusively engaged in small scale livestock farming. Despite landownership and farm production, income levels generally did not exceed the current legal monthly minimum wage in Colombia.

1.5 Case study approach

The research followed a single case design. The case was embedded, integrating more than one unit of analysis, and quantitative and qualitative methods (Scholz and Tietje, 2002). Data were gathered through different strategies: semi-structured interviews, surveys, focus groups, and documentary sources. Data collected were integrated using System Dynamics.

To address objective 1, *to understand stakeholders´ perceptions of the micro and macro factors affecting catchment health and human health and wellbeing*, Group Model Building (GMB) strategies were used (Vennix, 1999). The GMB approach was chosen because it is suitable in situations dealing with complex systems, multiple scales, multiple perspectives and ill-defined problems (Andersen and Richardson, 1997; Vennix, 1999; Andersen *et al.*, 2007). Stakeholders in this GMB process were staff from DCC. Data were collected from an initial review of documents, and semi-structured interviews conducted with staff. These data sources were used to identify: approach towards IWRM and EcoHealth; issues of concern regarding catchment health and human health and wellbeing; and to produce a preliminary Causal Loop Diagram (CLD) that summarizes stakeholders´ perceptions and knowledge about the system under analysis and its behaviour.

To address objective 2, *to analyse evidence on the behaviour of micro and macro socioeconomic and environmental factors related to catchment health and human health and wellbeing*, three surveys were carried out: i) household, ii) stream, and iii) drinking water. The household survey was applied to 100 households (40% of the population), that were randomly selected according to drainage area and water supply system. Questionnaires were administered through face-to-face interviews. This survey captured information on selected social determinants of health. The stream water survey comprised four monitoring campaigns in the rainy season and four in dry season. Water quality samples were collected at four sites, measuring eight parameters: Flow, pH, Temperature, Conductivity, Total Suspended Solids (TSS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Thermotolerant Coliforms (TTC). The drinking water survey involved 20% of the population in monitoring campaigns coinciding with the stream water survey. Samples were taken across the microcatchment, with a diversity of water supply alternatives. Water analyses included TTC, pH, Turbidity, and Chlorine residual. During sampling, people were asked about diarrhoea cases in any of the family members, in the previous 15 days. The stream and drinking water surveys captured information on the environmental determinants of health, and health outcomes, measured through the indicator of diarrhoea prevalence.

To address objective 3, *to develop a participatory systemic model that contributes to improve understanding of the relationships between micro and macro socioeconomic and environmental factors on catchment health and human health and wellbeing*, System Dynamics Modelling (SDM) was used for its ability to contribute to identify the problem, connections between factors, and policy levers. SDM aids to test theories, develop hypotheses (Winz *et al.*, 2009; Richardson, 2011; Mirchi *et al.*, 2012), learn how complex systems work, visualize feedback processes, and inform decision-making (Vennix, 1999; Stave, 2002; Van den Belt, 2004). A range of methods were used for model building including: semi-structured interviews, focus groups, secondary and primary information, and synthesis and triangulation. Three focus groups meetings were carried out to develop model structure and define sessions with individual stakeholders. Secondary information was gathered as maps, charts, and survey data regarding each parameter in the model structure, and graphs, tables, or time series were prepared. Primary information not available from secondary sources was collected through the previously described surveys and fed as quantitative data on model parameters. Semi-structured interviews with stakeholders were carried out to refine model structure, and progress on quantification.

Data from semi-structured interviews, focus groups and secondary sources were analysed according to themes and relevance to the research objectives and the theoretical framework of IWRM-EcoHealth. Data from the surveys were analysed computing descriptive statistics in Excel and performing statistical tests with the freely available software R version 2.15.2 (http://CRAN.R-project.org). SD principles and tools were used to integrate the information collected through the primary and secondary sources described to build a semi-quantitative model. The model included components of diverse nature at multiple scales, linking environmental health and human health and wellbeing in *Calabazas*. The model was a strategy for knowledge integration, synthesis and analysis, which complemented the methodological triangulation introduced with the mixed methods approach.

The model consists of socioeconomic and environmental factors, which are measurable indicators of key aspects relevant to understand human health and catchment health in the study microcatchment. The factors are linked together depicting relationships, with dimensional consistency. The behaviour of most of the factors or their initial value for the year 2013 was established, either through collection of primary or secondary data, consultation with stakeholders, or triangulation of the different information sources. However, limitations on the availability of historical information for the factors and lack of understanding of key relationships between these factors in the study microcatchment did not justify to write dynamic equations. Therefore, the model is mainly conceptual and it does not perform simulations.

1.6 Thesis structure

This document comprises six chapters, of which this introduction is the first. Chapter 2 provides a review of the key concepts on which the research builds: Adaptive Management, IWRM, EcoHealth and SD. This chapter establishes linkages between these concepts, and place the research within the scholarly literature. Chapter 3 describes elicitation of mental models of the relevant stakeholders to achieve a CLD for an initial representation of the system under study (Objective 1). Chapter 4 reports in detail the behaviour of socioeconomic and environmental factors that comprise the developed system structure (Objective 2). Chapter 5 uses SD for the integration and synthesis of the diverse system´s components, through a participatory modelling process (Objective 3). Finally, Chapter 6 recapitulates aims and summarizes key results, together with the research´s contributions to theory, policy and practice. Limitations and future work are also addressed in the last chapter.

Chapter 2. Literature Review

2.1 Introduction

This chapter reviews the concepts that frame this research: Adaptive Management, Integrated Water Resource Management (IWRM), EcoHealth and System Dynamics (SD). The research overlaps these concepts, since the catchment is the analysis unit (IWRM); it addresses the linkages between the environment status and human health and wellbeing, using diarrhoea as a health outcome indicator (EcoHealth); and these linkages are explored using SD as integrative tool. This review includes these concepts, and linkages between them, placing the research within the scholarly literature. Figure 2-1 shows a representation of the concepts studied and selected references within them.

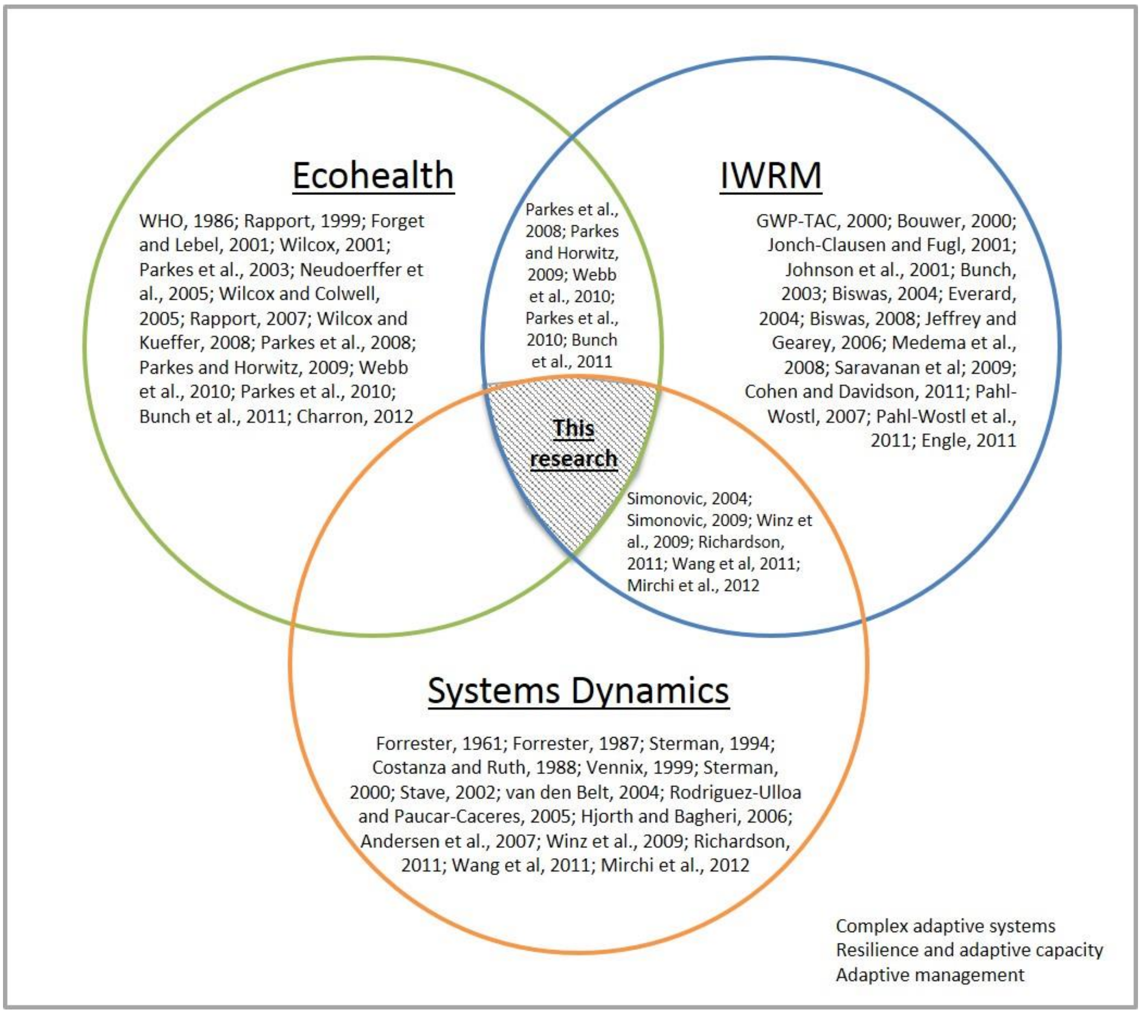


Figure 2-1 Literature review scheme

This chapter comprises four sections dealing with the above mentioned concepts. In each section premises, domains and debates are synthesized. At the end of the chapter, the research gap is stated and core aspects of the review are summarized as conclusions.

2.2 Adaptive Management, a crosscutting concept

Adaptive Management (AM) is a systems-based approach to environmental and resource management in situations characterized by uncertainty and complexity (Pahl-Wostl, 2007a). In AM, ecosystems are seen as complex systems, which are "adaptive", and "self-organising", in which management systems must be able to adjust to change and surprise (Jeffrey and Gearey, 2006).

According to Folke (2006), AM originates around the 1970s in the field of Ecology and it extended to areas like anthropology, ecological economics, non-linear dynamics, modelling of complex systems of humans and nature, environmental psychology, among others. The theory informed studies on ecosystems management, particularly large-scale ecosystems (e.g. terrestrial, fresh water and marine), and its development meant a shift in the management paradigm, from one based on equilibrium, and command and control strategies to regulate a target resource, to one that emphasizes learning to manage by change. The approach builds on the concepts of complex adaptive systems, social – ecological systems, resilience and adaptive capacity.

2.2.1 Complex Adaptive Systems

Systems are defined by Costanza *et al.* (1993) as *"groups of interacting, interdependent parts linked together by exchanges of energy, matter and information".* They also identify features of complex systems: *"Complex systems are characterized by strong, usually nonlinear, interactions between the parts, complex feedback loops that make it difficult to distinguish cause from effect, and significant time and space lags, discontinuities, thresholds, and limits".* Besides these characteristics, Complex Adaptive Systems (CAS) have the ability to adapt to a changing environment (non-equilibrium), by themselves (self-organization) through a set of critical controlling processes (Holling, 2001). The changes suffered by CAS depend on accidents of history; therefore, multiple outcomes are possible from those changes (Pahl-Wostl, 2007b).

Levin (1998) describes four basic properties of CAS: aggregation, non-linearity, diversity, and flows. Aggregation refers to the ways in which individuals are organized in groups. Patterns of aggregation and hierarchies are consequence of self-organization and essential in system development. Non-linearity means that local rules of interaction between components change as the system evolves, and the potential for alternative development pathways. Diversity refers to critical processes, and small set of elements that ensure the maintenance of system functioning. Flows provide the interconnection between parts, creating an ecosystem in which biotic and abiotic elements are interrelated (Levin, 1998). Folke (2006) points out the study of CAS is intended to understand how complex structures and patterns of interaction arise from disorder through simple but powerful rules that guide change.

AM theory focuses on the study of CAS, particularly coupled human-nature systems (Liu *et al*., 2007), socio-ecological systems (Anderies *et al*., 2004; Young *et al*., 2006; Ostrom, 2009), or social-ecological systems (Folke, 2006). These systems regardless the term, are linked systems of humans and nature. Its study emerges from the awareness that focus only on the social dimension or only on the ecological dimension of environmental management lead to narrow and wrong conclusions (Folke, 2006). Socio-Ecological Systems (SESs) are CAS, that involve multiple subsystems, and are embedded in multiple larger systems (Anderies *et al*., 2004). The outcomes from these systems result from complex, non-additive interactions between different types of social and biophysical components (Cox, 2011).

CAS have the ability to respond to crisis, and adaptive capacity is a measure of the system's vulnerability to unexpected or unpredictable shocks (Holling, 2001). Adaptive capacity is a component of resilience. Resilience and Adaptive capacity are important characteristics of SESs, and the development of the AM theory has largely focused on these concepts. Thus, these attributes of SESs are described below.

2.2.2 Resilience and Adaptive capacity

In the development of AM, resilience has been linked to sustainability (Carpenter et al., 2001), and used in a variety of interdisciplinary work as a way of thinking, organize thought, and provide a context for the analysis of SESs. The resilience perspective has evolved out of observation, using models as tools for understanding and incorporating stakeholders in learning about ecosystem processes (Folke, 2006).

Walker *et al.* (2004) define resilience as *"the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks".* Carpenter *et al.* (2001) summarize three properties of resilience: (i) the amount of change the system can undergo and still remain within the same controls on structure and function (domain of attraction); (ii) the degree to which the system is capable of self-organization; and (iii) the degree to which the system can build the capacity to learn and adapt.

Adaptive capacity is a component of resilience that reflects the learning aspect of system behaviour (Carpenter *et al*., 2001), and its ability to prepare for stresses and changes or adjust and respond to disturbance (Engle, 2011). Walker *et al.* (2004) see adaptive capacity mainly as a function of the individuals or groups acting to manage the system to influence resilience. In contrast to resilience, considered a desirable or undesirable property (Carpenter *et al*., 2001), adaptive capacity is seen positive in most literature, associated to the ability of actors to influence resilience and allowing transformations to more desirable status, highly related to institutions and governance. It has been suggested, that adaptive capacity can be a unifying concept with higher potential for operationalization, and translation to decision makers, due to its emphasis on governance, institutions and management, that ultimately could foster sustainable solutions to natural resource management problems (Engle, 2011).

2.2.3 AM as a learning process

Sustainability depends on the capacity of managers to understand the properties that enable SESs to maintain their integrity despite change (Levin, 1998; Pahl-Wostl, 2007b). Carpenter *et al.* (2001) explain that AM acknowledges that the quality and availability of resources will always change because of human intervention, surprises and uncertainty. Therefore, management demands flexible processes on policy implementation.

AM provide this flexibility, as a systematic process in which policies and practices are continually modified and flexible for adaptation to surprises, as result of learning from the outcomes of the implemented strategies (Pahl-Wostl, 2007a; Pahl-Wostl, 2007b). In AM, learning is central, and advanced by institutions interested in test hypothesis, anticipate the effects of management actions, formulate plans, monitor, evaluate, update and modify strategies based on the process outcomes (Carpenter *et al.*, 2001; Bunch, 2003; Pahl-Wostl, 2007b; Medema *et al.*, 2008). This process aims for improvement and allows policy makers and resource managers to increase the pace and frequency to acquire knowledge about ecological relationships; increase the effectiveness of managerial decisions; and enhance information flows and shared understanding among different stakeholders (Medema *et al*., 2008).

Limitations to implement AM have been found by Medema *et al.* (2008), including: little or no flexibility in the institutional system within organizations to adopt the approach; lack of capacity and willingness for implementation; lack of support and commitment from stakeholders during the learning cycle; lack of long-term sources of funding to develop the required learning cycles; limited understanding of how to apply AM and difficulties in translating results from site-level projects to larger scales.

AM concepts, also known as the ecosystem approach, have permeated areas of knowledge that also deal with CAS and management of natural resources. Some of these areas are IWRM, EcoHealth, and SD, which are discussed in the following sections.

2.3 Integrated Water Resource Management (IWRM)

The recognition of the significant role of water in industrial, agricultural, economic, social and cultural development has led to the proposal of strategic managerial approaches such as IWRM (Jeffrey and Gearey, 2006). IWRM emerges from the concern with the increasing problems surrounded water and the acknowledgement that effective solutions require more than technical approaches, cross-sectoral involvement, and public participation. Under IWRM, the catchment is considered the logical managerial unit, throughout which all decisions and actions have interdependent ecological, social and economic implications (Everard, 2004).

Evidence of the use of the catchment concept has been traced back to the third century in China. In the 20th century, the approach was primarily driven by expertise in hydrology and engineering, and later in the 1950s, elements such as human use and distribution of cost and benefits into the hydrologic model led to the concept of IWRM (Cohen and Davidson, 2011). IWRM was promoted in the 1950s by the United Nations and revived by water professionals at the beginning of the 1990s (Biswas, 2004). Some milestones are the United Nations Conference in Mar del Plata - 1977 (Biswas, 2004), and Dublin and Rio de Janeiro Conferences - 1992 (Jonch-Clausen and Fugl, 2001). From the 1990s, IWRM was intensively promoted, the Global Water Partnership (GWP), being one of the leading advocators. GWP formulated a definition, produced documents as tools for implementation, and facilitate initiatives across countries aiming at its adoption (Jeffrey and Gearey, 2006; Biswas, 2008).

GWP formulated the most widely used definition of IWRM in 2000 (GWP-TAC, 2000): *"IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".*

Jonch-Clausen and Fugl (2001) explain the IWRM definition by GWP, focusing particularly in the meaning of "integrated", to strengthen the conceptual basis for IWRM. They propose the starting point should be the hydrological cycle, and claim IWRM is a process of balancing trade-offs between different goals in an informed way. The goals are: economic efficiency in water use, by recognizing that both water and financial resources are finite; social equity, by appreciating all people have the right to access water in quality and quantity to support their wellbeing; and environmental and ecological sustainability, by understanding the role of water to support associated vital systems for present and future generations. They suggest achieving these goals result from a process of political negotiation and coordination, coordination being the element that ensures moving from a fragmented sub-sectoral towards a holistic cross-sectoral approach.

Jonch-Clausen and Fugl (2001) were among the early pioneers of a debate on what "integration" means in IWRM, discussing what to integrate, but giving few ideas on how to do it. This debate provided different insights to IWRM in the last decade. Primarily, they proposed the integration between the natural system and the human system. The natural system determining the availability and quality of water resources, and the human system influencing resource use, waste production and pollution and setting priorities for management. Additionally, they suggest various categories of integration: land and water; surface and groundwater; quantity and quality; upstream – downstream water related interests; freshwater management and coastal zone management; human systems (economic, social and political); water and general economic development planning processes; water resource planning with poverty alleviation; water considerations in to the planning process for interrelated sectors; national security and trade policies; different managerial levels; stakeholders; and sectors.

Despite this focus on integration, in which IWRM must consider "*all pertinent factors in the decision making process"* (Bouwer, 2000), initially, the proposed solutions were generally technical and economical. Later, factors like users' participation on catchment management as a strategy to achieve effective delivery became relevant. This resulted from the reflection on the failure of projects that concentrate on technical and economic aspects, ignoring people needs, knowledge and practices (Johnson *et al.*, 2001). Another argument put forward for broad participation was the acknowledgement that watershed management strategies represent different outcomes to different users, creating the need for spaces in which stakeholders jointly negotiate, set priorities, evaluate alternatives, implement and monitor results. Participation was seen as a mechanism to recognize local knowledge and allow people to reflect and understand how processes on complex systems like catchments occurs and thus, to foster people to change their ideas about desirable and feasible management alternatives (Johnson *et al.*, 2001). In recent decades, participation has increasingly gained importance in water resource management, and it is considered that participatory processes can help to integrate different perspectives and interests, increase understanding of complex water problems, devise more legitimate and effective solutions, and generate commitment. It is believed these features facilitate implementation of the required strategies to better water resource management (Carr *et al.*, 2012).

The GWP formulated packages of managerial instruments, a "Toolbox", aimed at IWRM implementation. In developed countries the tools focused on water quality and quantity, whereas in developing countries an element of poverty alleviation was included (Saravanan *et al*., 2009). The statements and tools produced by GWP identify three main components required for successful implementation: i) policies, legislative frameworks and financing (enabling environment); ii) an institutional framework; and

iii) a set of managerial instruments for gathering data and information, assessing resource levels and needs, and allocating resources for use (Jonch-Clausen and Fugl, 2001; Medema *et al.*, 2008; Saravanan *et al.*, 2009). According to GWP, these components are the base for the governance conditions to successfully implement IWRM.

2.3.1 Debates around IWRM

A number of authors claim IWRM became fashionable and even the norm in water resources management, being adopted explicitly or implicitly by national and international organizations (Biswas, 2004; Jeffrey and Gearey, 2006; Biswas, 2008; Saravanan *et al.*, 2009). According to IWRM critics, this widespread acceptance occurred despite of the problems with the GWP definition itself (Biswas, 2004; Biswas, 2008); the lack of solid theoretical basis (Jeffrey and Gearey, 2006; Medema *et al.*, 2008); the lack of sounding empirical evidence and probed methodologies that support implementation (Biswas, 2004; Jeffrey and Gearey, 2006; Medema *et al.*, 2008); the challenge to achieve legitimate participation and accountability, and even the difficulties to use hydrological boundaries to manage water (Cohen and Davidson, 2011). An insight on these criticisms is provided below:

- Biswas (2004) claims most organizations endorsed the IWRM concept without serious analysis of its meaning and possibilities for implementation. He argues IWRM diffuse definition is full of other "diffuse" words (e.g. economical welfare, equitable, sustainability, vital systems); and people call IWRM a variety of things. He emphasizes the problem of integration, by identifying 41 sets of issues that authors consider should be integrated under IWRM and argues this amount of aspects is not possible to be considered even at the conceptual level (Biswas, 2004; Biswas, 2008). Saravanan *et al*. (2009) contribute to this debate, by providing evidence on the diverse connotations, definitions and approaches to IWRM, only with the commonality of the catchment as the place where multiple actors in a hydrological unit make decisions.

- Some authors suggest IWRM lacks of a solid theoretical foundation, and is only a normative theory, and a set of principles to water management (Biswas, 2004; Jeffrey and Gearey, 2006; Saravanan *et al.*, 2009).

- Biswas (2004) believes the guidelines prepared by GWP to help IWRM implementation lack of objective assessment; defined parameters, methodology and criteria that provide clear indication of when IWRM exists. Others highlight, there is lack of models, operational methodologies with successful results, lack of empirical evidence or poorly reported experiences, demonstrating convincingly IWRM benefits (Jeffrey and Gearey, 2006). Furthermore, Medema *et al.* (2008) identify lack of workable institutional arrangements, planning tools, management strategies, and human and institutional capacities.

- Saravanan *et al.* (2009) call to realistically analyse the obstacles to achieve real participation in IWRM. Obstacles observed include the high likelihood of involving direct and easily identifiable stakeholders, legitimizing existent resource use patterns, deprivation of the vulnerable, exacerbation of conflicts; and lack of institutional capacity and accountability to develop adequate participatory processes.

- Other criticism is the inadequacy of the use of the hydrological boundary itself. Cohen and Davidson (2011) identify three challenges in this regard: i) watershed boundaries are incongruent with other natural system boundaries; ii) jurisdictions in which governmental participants in watershed-scale initiatives are accountable mismatch with the watershed boundary; and iii) watersheds and the geographic area over which governmental entities have legislative authority are asymmetric. They propose the watershed should be a policy choice, rather than an unquestionable scale for water governance initiatives, and to consider the utility of watersheds for IWRM as a function of the context of application. Johnson *et al.* (2001) state the need of flexibility in "*allowing watershed users to identify the boundaries and scales at which they prefer to organize themselves without insisting on geo-hydrological or existing social and political boundaries and scales"*.

2.3.2 The complexity of IWRM

The complexity of IWRM has been identified as one obstacle to implementation (Jeffrey and Gearey, 2006). This is evident on aspects like: the still unknown cause-effect relationships between water development - management - economic and social welfare; and the knowledge specialization that inhibit integration (Biswas, 2004).

Saravanan *et al.* (2009) question the abundance of criticisms to IWRM without providing constructive alternatives, and as a way to move forward propose to combine a pragmatic approach with a normative approach to allow implementation. For them, the pragmatic approach must recognize IWRM as a complex adaptive process in which multiple actors take decisions, is context-specific and influenced by historical processes, social context, ecological factors, and dynamics of power exercised by different actors.

The acknowledgement of watersheds as complex systems, and the criticism to the lack of implementation have resulted in the introduction of adaptive capacity and AM concepts to the IWRM discourse (Bunch, 2003; Jeffrey and Gearey, 2006; Engle, 2011; Pahl-Wostl *et al.*, 2011). Johnson *et al.* (2001) recognize watersheds as complex systems in which AM is required to undertake cyclical learning process to design, implement, monitor and evaluate, reflect and revise in both research and management endeavours. AM offers a framework to increase the adaptive capacity of water systems through these cyclical learning processes (Pahl-Wostl, 2007b; Medema *et al*., 2008). In water systems, AM aims at enhancing adaptive capacity to increase the ability to respond to change rather than reacting to undesirable impacts of change (Pahl-Wostl, 2007a).

Pahl-Wostl *et al.* (2011) illustrate how scientific, policy-makers and practitioners have tried to move from a “command and control” water management paradigm based mainly on technical solutions to water problems, to an “integrated-adaptive management” paradigm. The “integrated-adaptive management” paradigm recognizes water management deals with CAS and ill-defined problems. This awareness results from the need to implement IWRM in a context of socioeconomic and environmental change and uncertainties (Pahl-Wostl, 2007a; Pahl-Wostl *et al.*, 2011). However, the combination of IWRM and AM requires turning the argument for how enquiry and intervention should proceed into evidence and management tools to support implementation (Pahl-Wostl, 2007b; Medema *et al.*, 2008; Engle *et al.*, 2011). Pahl-Wostl (2007a) explains this difficulty is consequence of prevailing mental models within the water sector actors, and indicate that systems thinking tools could be useful to address management problems in CAS.

2.4 EcoHealth

EcoHealth emerged as a response to traditional engineering and economic approaches to environmental management (Rapport, 2007), looking to extend the concept of health from its traditional domains of application at the individual and population levels to the ecosystem (Rapport *et al*., 1999). The early history of EcoHealth dates back to 1788. However, the concept and term only became widely used in 1990s with applications of "healthy ecosystems" to forest, rangeland, coastal, and freshwater management (Rapport *et al.*, 1999; Webb *et al.*, 2010). The development of the field has been informed by disciplines like anthropology, epidemiology, public health, geography, and ecology (Bunch *et al.*, 2011).

EcoHealth attempts to overcome the compartmentalization of the health and environmental policies that ignores the dependency of human health and prosperity on healthy environments (Charron, 2012), and aims to provide environmental and health policymakers and practitioners with a theoretical framework, methods and practical tools, to improve society's ability to sustain life-supporting systems (Wilcox, 2001). The approach is considered relevant to address health concerns of vulnerable populations, social determinants of health, global health inequities, climate change, and food and water resources management (Webb *et al*., 2010).

EcoHealth researchers have defined their understanding of health and ecosystems to have common operational definitions. Thus, health is based on the World Health Organization (WHO) definitions (WHO Constitution 1948 and WHO 1986), which are broad, considering the influences of human living conditions and ecosystems over human health. This broader perspective results from recognizing the limitations of the clinical approach, which despite its successful role in reducing infectious disease during the twentieth century, has not been sufficient to address issues such as the relations between people, their physical environment, and disease, particularly in the developing world (Forget and Lebel, 2001; Neudoerffer *et al.*, 2005; Charron, 2012). EcoHealth demands consideration of aspects that traditionally are beyond the health sector boundaries, like education, nutrition, livelihoods, and gender, reflecting the need for an ecosystem approach (Forget and Lebel, 2001). Under this understanding, health is mostly assessed at a community or sub-group level (Charron, 2012), and recognized contextual, and dynamic (Rapport *et al*., 1999). Within EcoHealth, health is also used in a metaphorical sense, referring to healthy environments (Charron, 2012).

With regards to the understanding of ecosystems, although there is not an agreed definition (Forget and Lebel, 2001), a common feature across proposals is a set of different living organisms dynamically interacting with their physical environment (Forget and Lebel, 2001; Charron, 2012). For planning and information gathering, the limits of a given ecosystem are defined by the user, according to the problem under study and its scope. While in general, the limits of the ecosystem will be within an ecological space, such as a watershed or a region, an ecosystem can also be a farm, an urban subdivision, a riparian zone, an irrigation scheme, or a rural community (Forget and Lebel, 2001; Charron, 2012).

Within EcoHealth the ecosystem approach is recognized, and ecosystems are seen as complex systems for which system thinking tools contribute to increase understanding on behaviour (Charron, 2012).

2.4.1 EcoHealth principles

EcoHealth looks at the enabling circumstances under which ecosystems maintain their full functionality, while providing sustainable livelihoods, wellbeing, economic opportunity and equity, social justice and human health (Rapport *et al.*, 1999; Rapport, 2007; Wilcox and Kueffer, 2008). In EcoHealth, human health and wellbeing are dependent on ecosystems and important outcomes of effective ecosystem management (Forget and Lebel, 2001; Parkes *et al.*, 2010; Bunch *et al.*, 2011).

The approach has six main principles (Charron, 2012): (i) system thinking, (ii) transdisciplinarity, (iii) community participation, (iv) sustainability, (v) gender and social equity, (vi) knowledge in action. Forget and Lebel (2001) and Charron (2012) describe these principles:

Systems thinking: provides a framework and tools for the holistic analysis of health. It allows understanding the complexity of health, in the context of SESs, involving consideration of ecological, sociocultural, economic and governance dimensions and their relations. In addition, it facilitates richer stakeholders participation and integration of knowledge from different fields to better understand the limits of the problem, its scale, and its dynamics, leading to more effective processes (Charron, 2012).

Transdisciplinary Research: involves integration between disciplines, and non-academic perspectives and knowledge on EcoHealth initiatives (Forget and Lebel, 2001; Charron, 2012). This variety of contributions enrich problem analysis and solutions (Forget and Lebel, 2001), increase understanding of health in the context of SESs, and the possibilities to devise contextually appropriate strategies (Charron, 2012). This transdisciplinary approach provides a platform for stakeholders participation, and allows creating acceptable processes for discussion and negotiation (Charron, 2012).

Participation: ensures that local concerns, needs and knowledge are considered within processes, which contribute to formulate interventions to address environmental and related human health problems, that improve living conditions of local communities (Forget and Lebel, 2001; Wilcox, 2001). Stakeholders' participation enhances the possibilities of using new knowledge and implementing actions emerging from the research process as possible solutions to problems. Participatory processes also help to identify barriers to change, clarify information and knowledge gaps, and provide means to negotiate concrete steps for improvement (Charron, 2012).

Sustainability: EcoHealth aims to make ethical, positive, and lasting changes to improve human health and wellbeing for the current and future generations. To achieve this purpose, EcoHealth addresses local concerns and the wider forces that maintain cycles of poverty, environmental degradation, and disease (Charron, 2012).

Gender and Social Equity: EcoHealth explicitly addresses unequal and unfair circumstances between members of different groups in all societies that threaten their health and wellbeing. These differences are reflected in exposure to different health risks, health status, education, work, and living environment, among others (Forget and Lebel, 2001; Charron, 2012).

Knowledge to Action: in EcoHealth, knowledge from research is used to improve health and wellbeing through an improved environment. It recognizes that in participatory process, the situation may change while new knowledge (not-perfect knowledge) is being produced over time, through a series of research–action cycles. These cycles are dynamic and iterative processes of synthesis, dissemination, exchange and ethically sound application of knowledge (Forget and Lebel, 2001; Charron, 2012).

2.4.2 EcoHealth as a systemic approach

EcoHealth practice has evolved around two domains. In the first domain, the interest is to develop assessments and formulate indicators that involve ecological and social dimensions, to identify dysfunctional and fully functional ecosystems (Rapport, 2007), and propose interventions to restore ecosystem health (Wilcox and Kueffer, 2008). The second domain is a systemic approach (Forget and Lebel, 2001), in which human health is viewed from an ecosystem perspective, and systems thinking is used to facilitate understanding on the connections between nature, society, and health and how social and ecosystem drivers influence human health and wellbeing (Wilcox, 2001).

EcoHealth and other integrated research approaches such as resilience agree on the concept of SESs, where humans are seen as part of their environment, influencing and being influenced by it. Under these ideas, population health and wellbeing are outcomes of complex and dynamic interactions between people, social and economic conditions and ecosystems. Likewise, ecosystems conditions are affected by dynamic interactions, influenced by peoples´ actions (Charron, 2012).

Wilcox and Colwell (2005) see a high potential in EcoHealth to address some challenges like infectious diseases, particularly in the developing world. They explain how, in spatially contagious processes, demographic, social, and landscape transformations occurring on the scale of a regional system over a period of decades or more, interact with changes in host–parasite/pathogen dynamics that occur on the scale of a single catchment area, with a periodicity of days or months. These cross-scale mechanisms produce regional or global-scale disease emergence patterns for which conventional epidemiology strategies are limited. In contrast, these cross-scale processes are characteristic of SESs, potentially better addressed by approaches from resilience or AM. Bunch *et al.* (2011) explain synergies between EcoHealth and resilience theories to address health and sustainability concerns across scales from individuals to communities and ecosystems. They argue in EcoHealth, ecosystems and social systems are understood as CAS, which are resilient, and may undergo rapid and surprising change.

In EcoHealth as a systemic approach, research can help to characterize the links between environmental deterioration and impacts on human health, and to propose interventions that halt ecosystem degradation or increase vitality. An action research approach is considered the better strategy to achieve this purpose, for its flexibility to refine and adapt interventions according to changing circumstances and values. It also contributes to increase stakeholders' understanding on the system, facilitating the adoption of effective interventions (Forget and Lebel, 2001).

2.4.3 EcoHealth and IWRM

Since its beginning, EcoHealth has seen water management issues from a systemic perspective. According to Webb *et al.* (2010), the first written record of the "ecosystem approaches" which dates back to 1978, states that *"water cannot be adequately managed without considering broader ecosystem and human–environment interactions"*.

The main argument exposed in favour of the connection between EcoHealth and IWRM is the advantages of adopting the catchment as the effective unit to link water and health management because of the nature of water as a "binding" element to the natural world and the anthropogenic world. The catchment also allows consideration of upstream-downstream issues, such as water quality, quantity, and provision and access to ecosystem services, determinants of human health and wellbeing (Parkes *et al.*, 2008; Parkes and Horwitz, 2009; Parkes *et al.*, 2010; Bunch *et al.*, 2011). Furthermore, the catchment as the analysis unit allows changing the traditional paradigm of health promotion through "settings", which ignores these "settings" are part of an ecosystem that heavily influences health, providing tangible contexts to fulfil overlapping objectives across fields (Parkes and Horwitz, 2009).

Bunch *et al*. (2011) consider the integration of EcoHealth and IWRM as a solution to the plethora of arguments on the lack of practical application of environmental management approaches. For them, this integration will allow developing implementation guidance to capture the strong synergies among ecosystem approaches to health promotion, natural resource management and poverty reduction. This approach applies systemic thinking to address the challenges of WRM (Webb *et al*., 2010).

Premises of the IWRM-EcoHealth integration

EcoHealth–IWRM promoters have put forward several reasons to adopt this paradigm:

- Catchments are functionally hydrologic units in which the water cycle is a key driver of ecosystem processes, making them idealized ecosystems to design strategies that address health, environmental and socioeconomic priorities (Wilcox, 2001; Parkes *et al.*, 2010; Bunch *et al.*, 2011).

- Catchments exhibit characteristics of SESs, which made them place-based units that facilitate understanding reciprocal relations between quality and quantity of water; complex processes of social learning, social and inter-generational health and equity, environmental change (Parkes *et al.*, 2010); and the provision and access to ecosystem services, determinants of human health and wellbeing (Parkes *et al.*, 2008; Bunch *et al.*, 2011). Where catchments mismatch with administrative boundaries, they provide a link between upstream and downstream issues of water management, highlighting the need for transparent and ethical arrangements required for multi-level and multi-scale problems (Parkes *et al.*, 2010).

- Watershed governance has strong potential to fulfil both ecosystem management and public health objectives. It involves consideration of livelihoods, land use, industrial and agricultural development, aesthetic and spiritual values, social equity, the environment, and human health (Parkes *et al.*, 2010; Bunch *et al.*, 2011). In consequence, governing watersheds for health and wellbeing have multiple benefits: allow identifying options for multiple synergistic uses of watersheds; encourage public and private sector to improve communities; reduce contamination and direct hazards; and enhance social capital (Parkes *et al.*, 2010). This view of health–water relationships goes beyond the traditional focus of water management on drinking water supply, sanitation, and contaminants, and add dimensions of water for livelihoods, employment, food service provision, culture and identity (Bunch *et al.*, 2011), and contribute to social–ecological resilience (Parkes *et al.*, 2010).

Bunch *et al*. (2011) bring attention to cases where the EcoHealth-IWRM integration can be beneficial, including: i) to address water related diseases, and ii) to enhance sustainable livelihoods in agricultural economies dependent on water. In the first case, they argue IWRM-EcoHealth holds potential to increase the understanding on key relationships between the ecosystem context and water-related diseases, allowing to devise interventions focused in a more preventive approach to restore ecosystem services and build resilience for both human and environmental health. This perspective involves cross-scale issues that require insights from ecosystem approaches.

In the second case, IWRM-EcoHealth is considered useful to help to understand and manage the linkages between livelihoods, poverty reduction and natural resources management. Under this perspective, watershed management is believed to have potential to decrease poverty and related drivers of health inequities, improve the social determinants of health, contribute to maintenance (or restoration) of ecosystem integrity, fostering sustainable livelihoods, equity, and social engagement, and offer a strategy to promote both human health and ecosystem resilience in coupled human and natural systems (Bunch *et al.*, 2011).

2.4.4 Debates around EcoHealth and IWRM-EcoHealth

As with other integrated perspectives, EcoHealth deals with issues regarding the variety of meanings and practices that emerge from it as an umbrella approach, particularly because the concepts of health and ecosystems also lack of agreed definitions (Wilcox, 2001). However, EcoHealth promoters have tried to define operative meanings for these concepts to allow the field to move forward.

The metaphor of healthy ecosystems has been criticized, and EcoHealth promoters have recognized ecosystems are not organized according to the same principles of humans, and explain, the use of the health concepts at the ecosystem level does not require making the analogy between ecosystems and organisms, but a recognition that ‘‘health’’ is a fundamental property of life systems (Rapport, 2007). Forget and Lebel (2001) claim to avoid the semantic debate and recognize the benefits the metaphor has served to create awareness and promote action against environmental degradation.

Particularly in the case of IWRM–EcoHealth, Bunch *et al.* (2011) argue that despite the value in explicitly addressing concerns about human health and wellbeing on a watershed basis, there are several challenges to this proposal. These include issues of jurisdiction, integration of academic disciplines, professional fields, multiple worldviews, spatio–temporal scales, and complexity of the different aspects of these SESs, including climate and atmospheric processes, land uses, ecological processes, social networks, livelihoods, and lifestyles. These challenges put forward the need to explore approaches to management that are more appropriate to complex situations. An ecosystem approach is considered suitable to the IWRM-EcoHealth integration, since it can provide resources, concepts and tools to understand these complex relations (Parkes *et al.*, 2003; Parkes *et al.*, 2010).

2.5 Systems thinking and System Dynamics (SD)

The analytical method to develop scientific knowledge in which problems are divided into components, to study isolated parts and then drawing conclusions about the whole, has been recognized to be ineffective to address modern problems. This awareness led to the emergence of the systems thinking paradigm, which focuses on the relationships among the system's parts rather than on the parts themselves (Hjorth and Bagheri, 2006). It is a transdisciplinary field, with several schools of thought, and applied to a variety of areas (Sterman, 1994), which provides a specialized language and tools that help to understand complex problems (Hjorth and Bagheri, 2006).

Systems thinking tools are intended to depict people's understanding of a particular system's structure and behaviour, communicate with others about this understanding, and design high-leverage interventions for problematic system behaviour (Hjorth and Bagheri, 2006). Some of the branches emphasize qualitative methods, while others focus on formal modelling (Sterman, 1994).

System dynamics (SD) is one branch within the systems thinking approach (Sterman, 1994; Hjorth and Bagheri, 2006; Mirchi *et al.*, 2012). SD is a method to understand the structure of the relations between components of complex dynamic systems over time (Sterman, 2000; Rodriguez-Ulloa and Paucar-Caceres, 2005; Hjorth and Bagheri, 2006). Its origins date from the 1960s when J. Forrester started the field of Industrial Dynamics (Richardson, 2011). Five premises informed the beginning of SD (Forrester, 1961; 1987; Rodriguez-Ulloa and Paucar-Caceres, 2005): i) the human intuitive judgement about how systems behave in time is unreliable even if the knowledge on the individual parts is comprehensive; ii) models can capture the complexity of the world and help to visualize how the separate parts of a system interact to produce results, contributing to fill the gaps of human incomplete knowledge and judgement; iii) the main structure of controlling policies and decision-making can be represented; iv) systems should generate within themselves their behaviour modes of interest (endogeneity); and v) policy and structural changes are possible to improve system performance.

Endogeneity is considered one the most crucial aspects of the SD approach (Richardson, 2011). Under this concept, the system is constructed in a way that problems cannot be attributed to independent causes from outside (Forrester, 1961; 1987). The system's dynamic behaviour arises from its internal structure, and variables and interactions essential to this behaviour must be included inside the system boundary. Endogeneity forces causal influences to form the loops that provide the system structure, and is this perspective what is useful to address global challenges (Richardson, 2011).

From its earliest applications to industrial systems (Forrester, 1961), the use of SD tools extended to address the behaviour of human, physical, technical systems, and real-life problems (Sterman, 2000). Later, the requirements for greater and more effective client participation resulted in the development of group modelling techniques (Vennix, 1999; Andersen *et al.*, 2007). SD has also been applied to public decision making process in environmental management (Stave, 2002), and water resources management for its potential to achieve consensus and results implementation (Van den Belt, 2004; Winz *et al.*, 2009; Mirchi *et al.*, 2012).

2.5.1 Characteristics of Complex Dynamic Systems

The dynamics of complex systems are determined by feedback processes, stocks and flows structures, time delays and nonlinearities (Sterman, 2000). Another important information to understand system dynamics is mental models, which are the institutional structures, organizational strategies and cultural norms that governed people´s actions (Forrester, 1961; 1987). Sterman (2000) describes the characteristics that cause dynamic complexity in systems:

- Tightly coupled: The actors in the system interact strongly amongst themselves and with the natural world.
- Governed by feedback: When an action is taken, there are intended effects, and non-anticipated side effects, which feedback may undermine the proposed policy. These effects are a sign of incomplete system understanding, result of the human inherent linear way of thinking. In complex systems, all dynamics arise from interaction of two types of feedback loops, positive (self-reinforcing) and negative (self-correcting). All systems are made of networks of these feedbacks, and all dynamics arise from their interactions.

- Nonlinear: In complex dynamic systems, due to multiple factors interacting in decision-making, effect is rarely proportional to cause. This is opposite to what occurs in linear systems, in which the response to every disturbance is the sum of the separate components of systems response (Forrester, 1961).
- Path dependent: System´s outcomes depend on the route of the actions taken.
- Self-organized: The dynamics of systems arise spontaneously from their internal structure.
- Adaptive: The capabilities and decision rules of the agents change over time, and people learn from experience.
- Counterintuitive: Cause and effect are distant in time and space while generally causes are explored near the events to find explanations.
- Policy-resistant: Obvious solutions to problems fail or worsen the situations due to lack of system´s understanding.
- Characterized by trade-offs: Long run response of a system to an intervention is often different from its short-run response, making high-leverage policies create “worse-before-better behaviour”, while low-leverage policies often generate transitory improvement before the problem grows worst.

2.5.2 System Dynamics models and tools

SD uses models to reveal and understand the behaviour of complex systems (Forrester, 1961; Sterman, 2000; Richardson, 2011). According to Forrester (1961), models help to fill knowledge and judgement gaps, that result when trying to deal with the nonlinear dynamics of complex systems, using ordinary processes of description and debate. Models contribute to expose uncertain behaviour characteristics, and the way the system parts interact to produce unexpected and problematic systems results. They contribute to test theories, develop hypothesis, and refine explanations of systems change (Winz *et al*., 2009; Mirchi *et al*., 2012). The resultant explanations guide decision-making processes, and help to explore implications and policy contradictions (Winz *et al*., 2009; Richardson, 2011).

To overcome the issue of human deficient understanding of system behaviour, SD uses tools such as maps, models and simulation (Richardson, 2011). These tools can be divided in qualitative or quantitative modelling tools. Qualitative tools assist with problem conceptualization, while quantitative tools allow investigating and visualizing the effects of different intervention strategies through simulation (Winz *et al*., 2009; Mirchi *et al*., 2012).

Qualitative modelling tools

Qualitative modelling tools are useful for describing the problem, its possible root causes, and solutions. These tools include: causal relationships, causal loop diagrams (CLD), stock and flow diagrams, reference modes and system archetypes (Mirchi *et al.*, 2012):

- Causal relationships are representations of relations between two variables A and B, which can be: i) reinforcing or positive (e.g. increase cultivated area leads to increase in water demand), and ii) balancing or negative (e.g. increase infiltration leads to decrease in runoff).
- CLDs are graphic representations of the relationships between interactive subsystems, and include feedback loops.
- Stock and flow diagrams characterize accumulation or depletion of stocks and flow of quantities in the system, and their representation precedes the quantification process.
- Reference modes are intuitive patterns of system's behaviour over time (e.g. linear growth, exponential decay, and oscillation).
- System archetypes are generic system structures showing common patterns of behaviour, made from combinations of positive and negative feedback loops (e.g. Limits to Growth, and Tragedy of the Commons).

Quantitative modelling tools

Simulation is an alternative to test qualitative models (Sterman, 2000). Simulations require to know conditions at one point in time, and use this information to compute the system state at the next point in time (Winz *et al*., 2009), allowing the analysis of system performance under different scenarios (Hjorth and Bagheri, 2006). Simulating a dynamic system requires models with equations describing dynamic change, and making explicit underlying model assumptions, uncertainties about system structure, and data gaps (Winz *et al*., 2009).

According to Sterman (2000), qualitative models that show causal relationships but omit parameters, functional forms, external inputs, and baseline conditions are hypotheses about system´s structure, which must be tested. Forrester (1987) and Sterman (2000) suggest that simulations are the only reliable way to test hypothesis and evaluate policies, overcoming the problems that emerge when system dynamics behaviour is addressed intuitively through debates, writing, or the learning feedback in the real world. Software like Stella, Dynamo, Vensim and Powersim are tools to develop simulation models. These tools use the principles of object-oriented programing and provide a set of graphical objects with their mathematical functions to facilitate the process of representing system structure and the development of computer code (Wang *et al*., 2011).

2.5.3 The System Dynamics Modelling (SDM) process

The SDM process could be divided in three broad steps: i) problem definition, ii) model building and iii) simulation and using the results (Forrester, 1987; Rodriguez-Ulloa and Paucar-Caceres, 2005).

i) Problem definition: The problem, issue or system whose behaviour needs to be corrected through a SD intervention is stated, and described together with its apparent causes and the relationships between them. These possible causes are framed into information–feedback loops (Rodriguez-Ulloa and Paucar-Caceres, 2005).

ii) Model building: the problem framed into feedback loops graphically captures the relationships between interactive subsystems. The resultant graphics (CLDs), made of words and arrows, became the model structure, extracted from the mental models of people familiar with the system (Winz *et al*., 2009). Stock and flow diagrams can be developed from the CLDs, to characterize accumulation or depletion in the system. Stock and flow representations precede quantification of the processes that have been accounted for in the CLD (Mirchi *et al*., 2012). Models are prepared using computer software (Rodriguez-Ulloa and Paucar-Caceres, 2005).

iii) Simulation and using the results: Once the model is built, people involved can explore and analyse scenarios to test different policies or decisions (Rodriguez-Ulloa and Paucar-Caceres, 2005). The improved understanding on system behaviour obtained from the model should be used to develop high leverage policies for improvement

(Sterman, 2000). Additionally, this improved understanding should alter the mental models of relevant people (Forrester, 1987).

These three stages are an iterative process in which client input is central from problem definition to implementation. Therefore, strategies such as group model building and public participation have been formulated to develop dynamic modelling processes that are more effective, transparent and accountable to stakeholders.

Group model building (GMB)

From its beginnings, SD involved groups in the model building process to capture their mental models, to increase possibilities of implementation of results and to foster learning processes (Vennix, 1999; Andersen *et al.*, 2007). The adoption of these strategies led to a stream with various approaches, including GMB (Andersen *et al.*, 2007). GMB emerged in the 1980s in the management field (Andersen *et al.*, 2007), and refers to a SDM process in which a client group is deeply involved in model construction (Vennix, 1999). Contrary to what was suggested by Forrester (1987), regarding the necessity of clear problem definitions, GMB is useful to address well defined or ill-defined problems and cater for divergent participants´ views (Vennix, 1999).

Vennix (1999) claims GMB helps to assimilate and integrate partial mental models into a holistic system description, forcing participants overcome own views, make their mental models explicit and test their problem definitions, by bringing to the surface implicit (causal) assumptions. This can be achieved, using techniques that allow working with client groups, particularly, facilitated face-to-face meetings in which client teams are directly involved in the different stages of the process. The resultant models serve two purposes: i) provide a realistic representation of the policy under study and ii) help teams to comprehend how the system to which they belong works (Andersen *et al*., 2007).

During the 2000s, GMB extended from the field of business management into areas such as environmental management, in which clients were the public who need to be involved in decision-making process related to the complex problems of natural resources. Thus, a movement of public participation in SDM emerged.

Public participation in environmental management using SDM (Mediated Modelling)

As has been shown, the origins of SDM and GMB relate to the need for solutions to improve organizational management. However, around 2000s authors such as Van den Belt (2000) and Stave (2002) explored the use of SD tools to build stakeholder participation in environmental management. Van den Belt (2004) called this SDM process involving greater public participation, Mediated Modelling (MM). Unlike GMB, when staff from the same organization addresses business problems, in MM, people from a variety of organizations, backgrounds, interests, and viewpoints address natural resource management concerns.

This new field of application was motivated by: awareness on the complexity of environmental decisions that involve scientific and technical issues, uncertainty, and a wide array of stakeholders; the fact that there are not best solutions to environmental problems; recognition of the different values of stakeholders and the variety of outcomes from implemented policies to different groups; acknowledgement on the lack of clarity of policies for most people; and the need for public representation in decision making for environmental management (Stave, 2002; Van den Belt, 2004).

SDM has been identified as a tool that help to overcome these challenges and contributes to effective public decision making in natural resource management. SDM offers a consistent and rigorous framework, facilitating stakeholders to identify the scope of the problem, system connections and policy levers, and if allowing for simulation, compare the effects of alternative policy options. Additionally, SDM may be a tool for learning, helping people discover how complex systems work, visualize feedback processes, revise and retest their ideas. Furthermore, process documentation provides transparency and openness. These characteristics are more likely to persuade stakeholders to implement decisions (Stave, 2002; Van den Belt, 2004).

There are many levels of stakeholder involvement in SDM: full engagement in the modelling process, experimentation with a complete model, or providing feedback in particular sessions. However, when it is expected that stakeholders implement model outcomes, they should be included in the process from the outset. Since SDM does not require any knowledge on the methodology, modelling or computer simulation, the approach can be used with any group of stakeholders (Winz *et al*., 2009).

Despite the benefits of public participation in SDM, several challenges have been identified. First, difficulties to ensure regular and constant participation from volunteer public members. Second, limited time for modelling process, normally subject to political time horizons, reducing process scope. Third, difficulties to influence mental models of amorphous stakeholders groups (Stave, 2002).

2.5.4 SDM in IWRM and EcoHealth

In IWRM, SDM has been used almost from its origin in 1960, aimed at integrating physical, social and economic factors to plan for intra and inter-sectoral, long-term, multi-disciplinary and multi-actor problems. In the late 1980s, the underlying concepts of SDM "amalgamated" in the IWRM approach, and during the 1990s, projects increasingly incorporated participatory methods, and applications became more varied due to software innovations (Winz *et al*., 2009).

Mirchi *et al.* (2012) identify three general approaches in which SDM has been used in WRM: (i) predictive simulation models; (ii) descriptive integrated models; and (iii) participatory and shared vision models. They point out that predictive simulation models quantitatively simulate the processes governing particular subsystems within a broader water resources system. Descriptive integrated models are more holistic, identifying and characterizing the main feedback loops among subsystems to facilitate testing and selection of water resources management plans and policies. Finally, participatory models are practical tools to promote shared vision planning, modelling, and learning opportunities for stakeholder groups. On the other hand, Winz *et al.* (2009) categorize WRM dynamic applications in five groups, according to foci problems: regional analysis and river basin planning, urban water, flooding, irrigation and pure process models.

Recent advances in SDM for WRM use Geographic Information Systems (GIS). As has been discussed, originally, SDM focuses on representing temporal processes and does not account for spatial dynamics. The coupling of SD and GIS allows better representation of both temporal and spatial processes, by using the competency of GIS for spatial modelling (Ahmad and Simonovic, 2004; Simonovic, 2009). This integration provides new possibilities for understanding complex systems in WRM.

2.5.5 Debates around SD

There are some debates regarding SDM, which extend to its applications to WRM:

- Qualitative Vs. Quantitative Models: Forrester (1987) and Sterman (1994) emphasize simulation as the only way to overcome the limitations posed by the lack of human capacity to deal with complex systems. In contrast, Vennix (1999) states that qualitative modelling alone can increase a group's information processing capacity. He provides evidence on cases in which quantification decreased the model's relevance for an audience or was misleading, and argues that, SDM effectiveness should not rely only on simulation, or ignores situations in which quantification is extremely complex, and highlights the importance of awareness on feedback processes on its own, which commonly results from qualitative modelling. He suggests, in the case of ill-defined problems, the use of diagrams aids understanding of complex structures, adds rigor to the analysis and group discussion, helps to identify feedback loops and serves as "group memory". Similarly, Mirchi *et al.* (2012) argue that extensive computer simulations should be performed only after a clear picture of the system has been established through conceptual models, and recommend particularly in the case of WRM, using diagrams to prioritize information gathering and holistic investigation of interactions and potential impacts of different drivers of a problem.

- The social dimension: Vriens and Achterbergh (2006) claim the social dimension is hardly explicit in SD theory or practice, despite the fact that SD-models are: (i) models of social systems; (ii) built in social systems as a social activity, and (iii) built for social systems, in the context of organizational, institutional or societal problems. They argue that the explicit understanding of the social dimension is required to know whether a SD model is appropriate for the social system for which it has been prepared.

- Usefulness: For Winz *et al.* (2009), a model is useful when it addresses the right problem at the right scale and scope, and represents appropriately system response. However, they believe, model usefulness and quality are subjective and interfere with objective measures, particularly when the level of uncertainty and complexity of the problem is wide. On the other hand, authors such as Rodriguez-Ulloa and Paucar-Caceres (2005) suggest the implementation of the changes proposed from

SDM is a non-solved problem, and claim that aspects such as cultural feasibility and systemic desirability are not being sufficiently analysed.

In EcoHealth, there are several references to the principles of systems thinking (Forget and Lebel, 2001; Neudoerffer *et al.*, 2005; Wilcox and Kueffer, 2008; Parkes *et al.*, 2010; Webb *et al.*, 2010; Bunch *et al.*, 2011; Charron, 2012), yet no specific use of SD. Likewise, in the emerging integration of IWRM-EcoHealth there are not evidence on SD models developed to address the topics of this approach. A more in-depth review of SD applications to IWRM and EcoHealth is presented in Chapter 5.

2.6 The research gap

Gaps in the research of health, taking into account environmental and socioeconomic dimensions include the need for developing protocols to collect and analyse data, and innovative data fusion techniques to support indicators for research, planning, and evaluation (Batterman *et al.*, 2009). In EcoHealth, the need to provide environmental and health policymakers and practitioners with methods and practical tools to improve the ability to sustain life-supporting systems has been identified (Wilcox, 2001; Charron, 2012; Standley and Bogich, 2013). In addition, the importance of research that contributes to clarifying stakeholders' interests and values, and to design problem-solving practices, adequate to particular contexts (Wilcox and Kueffer, 2008).

In IWRM, Parkes et al. (2010) widely discuss how IWRM prioritizes catchment management for addressing anthropogenic impacts on the provision of environmental services, poverty reduction, and equitable distribution of resources, but frequently ignores the health perspective. On the other hand, SD models developed in IWRM, using the catchment as system boundary, often include socioeconomic and environmental pressures on water quality to support decision-making (Guo et al., 2001; Payraudeau et al., 2002; Yu et al., 2003; Chen et al., 2005; Kashimbiri et al., 2005; Kato, 2005; Leiwen et al., 2005; Leal Neto et al., 2006; Odada et al., 2009; Qin et al., 2011; Venkatesan et al., 2011). However, these models typically overlook how the reduced water quality influences human health and wellbeing. Thus, the IWRM-EcoHealth integration could help to explicitly recognize how ecological, social and economic factors are determinants of human health and wellbeing, using the catchment context (Parkes et al., 2010; Bunch et al., 2011).

In IWRM-EcoHealth, Bunch *et al.* (2011) argue the approach holds potential to increase the understanding on key relationships between the ecosystem context and water-related diseases, allowing to devise preventive interventions to restore ecosystem services and build resilience for human and environmental health. They also suggest to use this framework to understand and manage the linkages between livelihoods, poverty reduction, social determinants of health, and natural resources management, using the catchment perspective. In this line, Parkes *et al.* (2008) identify the necessity to develop case studies at the catchment scale that involve interconnected social and ecological factors, multiple perspectives, and conflicting stakeholders´ views, interconnected at temporal and spatial scales. However, it is recognised that using the IWRM-EcoHealth approach poses challenges including: issues of jurisdiction, integration of academic disciplines, professional fields, multiple worldviews, spatio–temporal scales, and complexity, demanding that approaches more appropriate to deal with complex situations are explored (Parkes *et al.*, 2008; Parkes *et al.*, 2010; Bunch *et al.*, 2011).

A common feature among the claims of authors interested in environment-human health connections is the recognition of the relevance of a systemic perspective to facilitate understanding of the complex relationships between elements of diverse nature. Eisenberg *et al*. (2007) emphasize systems thinking as a tool for understanding how environmental changes influence health, and how it could help to overcome prevailing public health approaches, which typically assume independence of outcomes, limiting the causal links between exposure and disease to the individual level. Batterman *et al*. (2009) believe the system approach facilitates the analysis of interactions and feedbacks, and stress the importance of interdisciplinarity to achieve sustainable solutions to the problem of water related diseases in the developing world. Besides, systems thinking is one of the principles in which IWRM–EcoHealth is based as discussed in Sections 2.4.1, 2.4.2, and 2.4.3.

SD is a branch within the systems thinking approach, that provides a specialized language and tools that help to understand complex problems and systems behaviour, communicate with others about this understanding, and design effective policies (Hjorth and Bagheri, 2006; Richardson, 2011). SD has been widely used in WRM (Winz *et al.*, 2009; Wang *et al.*, 2011; Mirchi *et al.*, 2012), but has not been explicitly used in EcoHealth or on the IWRM-EcoHealth integration yet. In particular, participatory SDM processes such as GMB and MM offer consistent and rigorous frameworks for analysis of complex systems, with the added benefit of increased stakeholders participation (Stave, 2002; Van den Belt, 2004).

This research is an empirical application of the premises from the IWRM-EcoHealth approach. The aim of this research is to contribute to this emerging field to increase the understanding on the linkages between socioeconomic and environmental determinants of human health and wellbeing and natural resources management at the catchment level, testing System Dynamics as a methodology that helps to elucidate the connections between factors from different dimensions at different scales, involving multiple perspectives, disciplines, and integrating qualitative and quantitative data collection and analysis strategies.

2.7 Conclusions

IWRM and EcoHealth have emerged as ecosystem approaches as a response to the increasing need to integrate aspects of diverse nature at different scales to address issues of natural resource management and human health and wellbeing. Despite the fact, that broad perspectives are considered key to sustainability, criticism to the lack of practical application of these strategic approaches abound, in particular, regarding the ambitions of integration.

This chapter described IWRM, EcoHealth and its integration as ecosystem based approaches in which the systems thinking paradigm could contribute to increase understanding of the complex SESs they deal with. SD was presented as a branch of systems thinking, with potential to provide the field of IWRM–EcoHealth a practical framework and tools to elucidate complex social, economic and environmental linkages at the catchment scale, and potentially to identify, simulate, and implement strategic managerial decisions to address overlapping health, environmental and socioeconomic priorities.

SD could be part of the toolkit for IWRM-EcoHealth to further develop the field and support implementation. The following chapters present results of developing a SD modelling process in which socioeconomic and environmental factors were linked to increase understanding of catchment health and human health and wellbeing in *Calabazas*, a rural Andean microcatchment in Colombia.

Chapter 3. Stakeholders perceptions of catchment health and human health and wellbeing

3.1 Introduction

In rural areas of developing countries people face a number of complex and interrelated problems that affect their quality of life (Merrey *et al.*, 2005). The IWRM–EcoHealth integration provides a perspective to address issues of rural livelihoods, upstream-downstream water relations, governance, ecosystems, and human health and wellbeing. The approach is based on the principles of: systems thinking, participation, action research and transdisciplinarity, among others (Parkes *et al.*, 2010; Bunch *et al.*, 2011).

The need to address human health and wellbeing and its relation with the environment by integrating multiple dimensions, perspectives, disciplines, scales, and giving greater attention to distal causes (driving forces) is increasingly being promoted (Corvalán *et al.*, 1999; Ezzati *et al.*, 2005; Batterman *et al.*, 2009; Parkes *et al.*, 2010; Bunch *et al.*, 2011; Confalonieri and Schuster-Wallace, 2011; Charron, 2012). Sets of multidimensional indicators and indices have been one of the solutions to advance the understanding of systems´ state and designing managerial strategies to address a diversity of issues such as: urban health (Spiegel *et al.*, 2001), watershed health, (Walker, 1997; Reuter, 1998; Singh et al., 1999; Aspinall and Pearson, 2000; Schwenke *et al.*, 2003; Huang, 2011; Yuan and Yang, 2011), and stream health (Snyder *et al.*, 2005; Hascic and Wu, 2006; Langpap *et al.*, 2008). In some cases, indicators are identified with help from stakeholders involving different levels of participation. For instance, indicators are proposed by experts and researchers and informed to farmers (Walker, 1997) ; indicators are suggested by experts and communities assess their appropriateness (Spiegel *et al.*, 2001); or indicators and data collection strategies result from collaborative initiatives between experts and lay people (Corburn, 2003; 2007).

Despite the contribution of indicators to decision making processes, indicators alone are limited to provide insights on how factors interact to produce outcomes. Even though complexity is increasingly realized, institutions with responsibilities over the territory have an incomplete understanding of complex relations, operate with a fragmented approach (Merrey *et al.*, 2005), and most policy, research and management endeavours involve only a subset of considerations, limiting possibilities to achieve sustainable solutions (Batterman *et al.*, 2009; Parkes *et al.*, 2010). Bunch *et al.* (2011) argue that "*reciprocal interactions among ecosystems, society, and health demand a more integrated and systemic approach*".

System Dynamics (SD) provide tools that help to depict people's understanding of a particular system, identifying components from different dimensions and the relations between them (Sterman, 2000; Rodriguez-Ulloa and Paucar-Caceres, 2005; Hjorth and Bagheri, 2006). SD uses models that help to capture the complexity of the world and to visualize how the separate parts of a system interact to produce results (Forrester, 1961; 1987; Rodriguez-Ulloa and Paucar-Caceres, 2005). Although, systems thinking is one of the principles in which the IWRM-EcoHealth integration is based, SD, one of the systems thinking tools, has not been used before under this perspective.

SD models are primarily based on the mental models of the actors involved (Forrester, 1987; Sterman, 2000; Luna-Reyes and Andersen, 2003). According to Forrester (1987; 1992), the information to be used in model building may come from three sources: i) mental database, ii) written database, and iii) numerical database. The mental database contains information to develop model structure, and is especially concerned with policy, involving reasons why people react, decision-making processes, incentives, disincentives and policy contradictions. The written database, which includes published material, news, and documents, needs to be analysed and interpreted to be useful for identifying behaviour and trends. The numerical database comes from different sources and provides the model parameters necessary for quantification.

During the formulation stage, the modeller relies mainly in the mental and written databases as information sources (Forrester, 1987; Sterman, 2000). Stakeholders´ mental models are translated into a SD model with the aid of software packages, and provide model structure and behaviour. Models formulated based on people´s mental models may achieve more accurate system representation, and potentially greater impact (Forrester, 1992; Van den Belt, 2004).

Group Model Building (GMB) and Mediated Modelling (MM) are well regarded methodologies to achieve integration between disciplines and professions in the process of building SD models. GMB is a SD modelling process in which a client group, generally from the same organization, is deeply involved in model construction. In

GMB, mental models come from the written and the mental databases of this group (Vennix, 1999). As part of GMB, Andersen and Richardson (1997) recommend to conduct interviews with key managers to develop problem understanding, before starting workshops with an extended stakeholders´ group.

In MM, the SD model is created by a group of people from a variety of organizations, backgrounds, interests, and viewpoints, for which it has been used to address environmental problems (Van den Belt, 2004). According to Ford (2009), environmental modelling is best performed through interdisciplinary processes, in which local knowledge should be incorporated. MM can be considered a form of coproduction as defined by Corburn (2007). In coproduction, science is understood as dependent on the natural world, historical events, social practices, material resources, and institutions. Coproduction challenges traditional distinctions between expert and lay ways of knowing (Corburn, 2007), a feature that can be shared with SD, believed to erase boundaries between disciplines, and the ways of perceiving reality between sciences and humanities (Hjorth and Bagheri, 2006). Coproduction recognizes that lay people have an intimate knowledge of place, disease coping strategies and cultural traditions that allow them participate in policy-making (Corburn, 2007). Local knowledge does not replace nor devalue, but complements professional knowledge (Corburn, 2003; Lambert *et al.*, 2006; Corburn, 2007).

As in GMB, in MM, the process involves a stage of preparation in which introductory interviews are developed to capture stakeholders' perspectives or mental models (Van den Belt, 2004). These early interviews allow the modeller to: i) get an initial understanding of the problem; ii) identify the main variables; iii) clarify definitions, iv) elaborate on topics; and v) familiarize with the respondents´ language (Luna-Reyes and Andersen, 2003). This stage of the process relies heavily on qualitative data collection and analysis methods, and various authors have worked on ways to add rigor to this phase of the process (Luna-Reyes and Andersen, 2003; Kopainsky and Luna-Reyes, 2008; Ríos, 2008; Kim and Andersen, 2012; Yearworth and White, 2013).

In GMB and MM, the information collected from stakeholders´ mental models through qualitative methods, once synthesized, is the base for a preliminary model. This preliminary model serves as point of reference to present and interpret the participants´

perceptions (Van den Belt, 2004), and constitutes the starting point of the modelling process (Forrester, 1987; 1992; Hjorth and Bagheri, 2006).

This chapter addresses Objective 1, *to explore stakeholders' perceptions on catchment health and human health and wellbeing.* In addition, those perceptions are used to identify factors, connections and develop a preliminary Causal Loop Diagram (CLD) that provides the foundations for a semi- quantitative SD model. This chapter seeks to:

i. Explore the stakeholders´ approach to IWRM
ii. Discern the stakeholders´ approach to IWRM-EcoHealth
iii. Capture the stakeholders' perceptions on the pressing issues over catchment health and human health and wellbeing
iv. Identify the factors stakeholders perceive affect catchment health and human health and wellbeing
v. Articulate stakeholders' perceptions (mental models) in a preliminary CLD to help understand system's structure

3.2 Methodology

GMB was used to elicit stakeholders´ perceptions on catchment health and human health and wellbeing in *Calabazas* microcatchment, using the IWRM–EcoHealth framework. First, the stakeholders´ approach to IWRM was captured. Second, stakeholders´ approach to IWRM–EcoHealth was examined. Third, pressing issues over catchment and human health were identified. Fourth, relevant factors to address catchment health and human health were obtained. Fifth, linkages between the identified factors were established, and integrated on a CLD. The GMB approach was chosen because it is suitable in situations dealing with complex systems, multiple scales, multiple perspectives and ill-defined problems (Andersen and Richardson, 1997; Vennix, 1999). Stakeholders in this GMB process were staff from the Departmental Committee of Coffee Growers (DCC) from Valle del Cauca. Data collection strategies and analysis are described below.

3.2.1 Data collection

Data were collected from an initial review of documents (written database), and semi-structured interviews (mental database) conducted with the "client group" (DCC staff).

Documents prepared by DCC conceptualizing their approach to rural development and documents produced by them to apply for aid to undertake programs at the microcatchment scale were reviewed to understand the official position regarding areas related to IWRM-EcoHealth. Documents were retrieved from the institutional website or provided by staff during interviews.

Semi-structured interviews were carried out with DCC staff, following a snowballing approach (Robson, 2011), starting with the gatekeeper, appointed as Head of Extension Programs. Using this technique, the gatekeeper introduced the rest of the interviewees. From November 2011 to November 2012, three individual interviews and two group interviews were carried out with staff members at DCC´s headquarters in Cali. Participants had different disciplinary backgrounds: Agronomy, Sanitary Engineering, Agricultural Engineering, and Economy. The interviews were around two broad topics allowing for open-ended discussion: i) approach towards catchment management; ii) issues of concern regarding catchment health and human health and wellbeing. Details of the interviews are presented in Appendix A. The interviews were conducted in Spanish, were recorded and notes were taken. The interviews were transcribed using the computer software QSR Nvivo version 10 (www.qsrinternational.com).

Perceptions from lay people living in the microcatchment were captured through a household survey. The social worker from DCC assigned to the microcatchment helped to establish key contacts in the community. The research project was presented to local leaders, and permission was requested to undertake the activities, explaining carefully the research stages and the products to be delivered to local people. The household survey was carried out with 40% (N=100) of the microcatchment population to collect information from a wide range of issues. The survey contained 15 sections from A to O (Appendix B). Only data from Section I are reported in this chapter. A more detailed explanation of the methodology used in this survey is presented in Chapter 4, where most of its results are addressed. Section I was intended to capture local peoples´ understanding of a microcatchment, what was considered a healthy microcatchment, and their viewpoint on the more pressing issues regarding the environment, water and human health. In addition, perspectives on the causes of the identified concerns were elicited.

3.2.2 Data analysis

Documents and transcripts from the semi-structured interviews were coded with the computer software QSR Nvivo. In NVivo codes are called nodes (Welsh, 2002). This process involved identifying passages from the transcribed interviews to exemplify the following ideas that were selected as codes:

- approach to IWRM (origin, implementation process, opportunities and challenges)
- approach to IWRM-EcoHealth
- pressing issues over catchment health and human health and wellbeing
- catchment health factors
- human health and wellbeing factors

Once data from the interviews were coded according to the themes above, Nvivo was used to retrieve data organized according to those codes or themes. Themes were summarised and supplemented by relevant quotations. Only the relevant quotations were translated from Spanish to English. Although, Nvivo has tools that facilitate the interpretation of data once the coding is done (Robson, 2011), using Nvivo in this investigation was restricted to facilitate the process of transcribing interviews recordings, coding and retrieving the information grouped according to the different nodes or themes, which are Nvivo capabilities for data management.

Responses in the household survey were tabulated in Excel 2010 and graphs depicting frequencies were produced. Data were summarised according to:

- people´s understanding of a microcatchment
- people´s perceptions of a healthy microcatchment
- people´s perceptions of problems and causes regarding: the environment, water and human health
- catchment health factors
- human health and wellbeing factors

Catchment health and human health factors elicited from the mental and written databases of DCC were classified with the primary criteria based on dimension and the second on spatial scale (Tiberghien *et al.*, 2011). Six dimensions were selected: i) social, ii) environmental, iii) economic, iv) technical, v) institutional, and vi) health and wellbeing. Health and wellbeing was a special category since the investigation involves the EcoHealth approach. The spatial scales were: i) external, ii) microcatchment, iii) farm and iv) individual. Data provided by the community respondents to the household survey in Section I, related to their perceptions of environmental, water and human health problems and their causes were grouped according to the same categories used for DCC staff (dimension and scale). Factors elicited from institutional and community stakeholders were synthesized through diagrams. In these diagrams, factors were grouped according to spatial scale and colours were used to differentiate factors according to dimension.

Factors elicited from DCC staff were connected using relevant quotes to represent stakeholders´ understanding and were used to produce a preliminary model structure (CLD), using the Vensim software. Mental models from DCC staff helped to represent the system. Contrary to semi-structured interviews, surveys do not allow to elaborate on topics (Knapp *et al.*, 2010), as required to elicit feedback loops, whereby it was not possible to build one CLD with the data from the community. However, local people knowledge and perceptions contributed further to system´s understanding, providing insights from a deeper contextual knowledge, and new perspectives to be used in later improvements to model structure.

3.3 Results

Results from the first stage of the GMB process are presented in five sections: i) stakeholders´ approach to IWRM; ii) stakeholders´ approach to IWRM–EcoHealth; iii) pressing issues over catchment and human health; iv) factors to address catchment health - human health; and v) structure of the preliminary qualitative model integrating factors and their connections (CLD).

3.3.1 Stakeholders approach to IWRM

The National Federation of Coffee Growers of Colombia (NFC) through the DCC provides various support services to farmers in *Calabazas* microcatchment, around the areas of coffee farm, community, connectivity and environment (FNC, 2010). DCC incorporated the IWRM concept and became a pilot for the NFC for implementing

IWRM. In the structure of the departmental committees at the NFC, farmers were served in administrative units "districts" that matched political boundaries, while in Valle del Cauca districts were microcatchments.

Origin of the paradigm shift

A reason why IWRM was adopted by DCC was the origin of the person leading the effort, the gatekeeper. Before being appointed as the Extension Director, he worked almost 20 years for the coffee research centre (Cenicafe), where part of his job involved being aware of the state of the art on issues around sustainability and how to introduce them to coffee farming[1] (Q1[2]).

> Q1: *"In Cenicafe I was head of dissemination and technology transfer. But most important to me was that I was invited to participate as a member of the research committee. Then I was able to have a great experience in the knowledge of all the trends of research and not only to know them, but to promote, approve or disapprove them".*

The adoption of IWRM was seen as a responsibility to minimize the impact the coffee industry was generating over natural resources in the department, particularly water. In addition, in an environment of coffee crisis, IWRM was considered an opportunity to leverage international funds to compensate for the resources the NFC was not generating from its business to work for the coffee farmers´ wellbeing, which is the *raison d'etre* of the organization. IWRM was perceived as a possibility to diversify coffee farmers´ livelihoods, by getting resources from the sustainable use of natural resources. Funds to advance the implementation process should come from international donors, since most of the country's institutions prioritized interventions to other sectors and resources were commonly allocated according to geopolitical boundaries (Q2).

> Q2: *"When I arrived here I participated in a discussion about water resources in Valle del Cauca, with the CVC[3] and … there was a point at which they addressed the sectors´ participation in Cauca river pollution. I was very surprised when I was told that 27 tons of BOD were provided by the coffee industry... I came back and I opened the Triennial Action Plan (from CVC) and I read it... and I had my story of what we were talking about sustainability… I started working on this a long time, it took me about four, five months, until I*

1 Unless it is indicated, quotations are from comments made by the Gatekeeper in different individual or group interviews in which he participated.

2 Q stands for Quote

3 CVC is the Environmental Authority for Valle del Cauca Department

made the proposal to the director. I checked in detail the subject of coffee growing evolution. We had lost many hectares. So what we have to do is reorganize this. To give context, to influence people´s mind-set, and generate indicators of sustainability for the coffee industry, as it is so complex, then access resources, because who is going to fund this? how? and where? Then… leverage international resources, because I imagined that nationally, locally, nobody has any money".

The IWRM concept held by the gatekeeper included elements of Complex Adaptive Systems (CAS), since he explicitly referred to the work on catchments taking a socio-ecological perspective. His premise was that using this approach all the organization´s interventions should be reflected on the catchment status. This would allow progress in achieving "verifiable" sustainable development (Q3).

Q3: *"Basically the approach was going to do a geographical, not geopolitical approach, based on microcatchments (to perform all DCC functions), and if we include communities within the microcatchments, we are not having a geographic focus but a socio–environmental focus… and everything we do should be reflected at the catchment scale... what we need to do is to insist, but in a verifiable sustainable development… because it became a cliché, everyone talks about sustainability…"*

Implementation process

The process to start the paradigm shift from working around political boundaries to working with hydrological boundaries, which was in progress, had five broad stages: get support from the senior management, update the Geographical Information System (GIS), undertake a biophysical characterization of microcatchments, appointment of extension workers, and implement pilot projects.

For the general manager, implementing IWRM was the materialization of his thoughts on how to address the environmental dimension within the organization, and he committed to provide support (Q4).

Q4: *"When we presented this (IWRM proposal) to the manager, he said if I would not know the status of my environmental ideas, I would say you got this idea from me. I had listened to his speeches (before), but surely there wasn´t a strong, specific proposal. Then he said, I declare that from this moment you are a pilot, and I will be monitoring how things evolve. Then he asked, what do you need to do this?"*

Updating the GIS was a key step, allowing that all the information they collected were managed at the microcatchment level, including the location of each of the coffee farms in the department with their associated information (acreage, age of coffee plantations, density, production system, coffee processing technology) (Q5).

> Q5: *"What we asked for (the manager) was a resource to finish updating the information system. We need georeferencing, because we worked under a geopolitical unit, but now we need to work with an ecosystem management unit"*

Each microcatchment was characterized according to their biophysical conditions, the relative importance of coffee (ratio area under coffee/total area), and the characteristics of the coffee produced in them (Q6).

> Q6: *"The next, which is work in progress, is a process of characterization of these units (microcatchments) and defining the attributes of the products that are obtained there, the relative importance of the land under coffee. There are microcatchments which have very good biophysical conditions for coffee growing and there are others not too good..."*

Administrative units were redefined and extension personnel assigned according to this new structure, and the relative importance of coffee in each microcatchment (Q7 – Q9).

> Q7: *"We had to build the structure of the district ... The district is where one works ... we asked: where the farmer is served? In one district, then what is a district?, how does it work? Then there were people who proposed the district was a village, a township. But I always fought because it was a microcatchment. If the district could not be a microcatchment… we would lost all the conceptual aspect of the catchment as a unit for development"*

> Q8: *"We thought we should reorganize because this had terrible consequences from an administrative point of view… we called the people (extension workers) in their districts managers and that had to make an impact… when we talked to agronomists, they petrified, because we told them we will assign them new territories and become managers… but the concept of management was power, make an administration, planning the district. Before they said my district is Tuluá (municipality), now they say my district is Catarina (river name). The key factor was the relative importance of coffee production in each catchment... and thus we assign responsibilities. Then there are microcatchments with two or three extension workers, or there are extension workers with two or three microcatchments"*

> Q9: *"The farmer is served in a district. The office is in the town centre, but the farmer is in the information system of the microcatchment and the agronomist in charge of the microcatchment is who attends the farmer"*

Finally, support was requested to be included in different calls to get funding to develop projects that allow progress in the construction of the model of coffee growing through microcatchments (Q10).

> Q10: *"We also asked (the senior manager) to be taken into account in projects or in the call for projects to apply or leverage international resources... from there, it comes the incorporation of developments, programs, investments, upgrade and management proposals of coffee growing, evaluations of product quality and technical work, but within the context of a different territory (the microcatchment)"*

Opportunities of IWRM

By incorporating IWRM, DCC started working on projects funded by international donors to develop the approach. One of these projects is "Sustainability of communities in healthy microcatchments", known as Peace Footprints (PFP) (Q11).

> Q11: *"Projects´ results will allow us to make practical associations. For example, how coffee growing should be at each microcatchment? This is a process that will never end ... You must have the concepts clear to use every opportunity from policy, support, management to give the approach… now we have peace footprints, coffee cultural landscape, coffee biodiversity, Payment for Environmental Services ... then the concept of the catchment is being incorporated to all of that..."*

In addition, IWRM was seen as an opening to achieve synergies, by working with other institutions with responsibilities for rural communities' wellbeing or natural resources conservation. Using the approach, DCC tried to work with CVC and the Society of water and sewage for Valle del Cauca (Acuavalle) (Q12 – Q13).

> Q12: *"Today everyone has to deal with applications for discharge permits, but CVC told us, the Ministry (of Environment and Sustainable Development) said we could apply for these permits by catchment or by microcatchment. This is crucial because all our approach fits... that's why I say you need to have the approach clear in your head to be able to see any opportunity... to introduce these ideas"*

Q13: *"Today we are approaching Acuavalle, which is a fundamental institution... and they welcomed the idea of our catchment management. Then one could say that Acuavalle is a potential ally in this policy. Because we are seeking to manage the issue of payment for environmental services..."*

In the long term, the aim was to build a model of sustainability in the rural areas, in which coffee farmers led the development of strategies in agreement with other actors with influence in the territory (Q14).

Q14: *"The idea is to see to what extent coffee communities could lead the development of the catchment… the model that should result at some point is a recommendation of management the territory towards sustainability, because of course, we frame this in coffee farming, but there are other actors with we have to agree with…"*

DCC were flexible and believed working with organizations that did not operate using hydrological boundaries was not a problem. DCC used the approach in a pragmatic way, the catchment was the first choice to undertake any intervention. However, if there was not support, they use the traditional geopolitical boundaries (Q15).

Q15: *"We switch easily from catchment to municipality, without a problem. That was the intention of having all georeferenced..."*

From their experience, DCC believed the catchment approach was at least: i) attractive, ii) less biased when prioritizing investments with limited financial resources, and iii) easily accepted when DCC obtained resources for projects and peer institutions made smaller contributions (Q16 – Q18).

Q16: *"I've travelled the Valle (del Cauca), showing the approach at the meetings of the municipal and departmental committees, and people really, really liked the proposal, and people clapped, it is the show"*

Q17: *"That was one of the big questions, how we would work with pieces of territory in the context of the decisions for instance, of a mayor, who is supposed to work for the whole community, but that has not been a problem ... as there is no money for everyone, you should always split somewhere. Splitting usually occurs by politics. In this case, it is easier because there is a much clearer justification, the microcatchment"*

Q18: *"...that (acceptance) is closely linked to the resources´ origin. When resources are international, you have to justify the project. Our justification is an intervention model for perfectly defined areas, catchments. Then, the donor* *chooses, says whether yes or not, is interested in this concept. So when I got a project and say this is for these catchments, people here have to accept it because it is what it is. So that way, I would say that poverty often determines acceptance"*

Challenges of IWRM

Despite the progress on IWRM implementation within the organization, several challenges remained; one of them was the lack of resources to monitor the impact of interventions. In a context where resources were insufficient to DCC due to the coffee crisis, interventions were subject to donor restrictions. For example, in PFP, the donor did not allow to use resources for a baseline that would measure water quality before and after the proposed interventions (Q19).

> Q19: *"The impact that we (coffee growers) are generating in the catchment is quite remarkable, and that is precisely why this is subject to investigation for us... however, nothing has been measured… but it is theoretical, calculated… they (CVC) have some evaluations. Basically, with the area, the hectares, a mathematical inference is done, theoretically… we know we have many hectares of coffee plantations of a certain type that is generating a type of pollution, according to the levels of productive infrastructure... Because you know, you cannot isolate pollution, because you have a great pollution to the Cauca River (from all sectors), equivalent to about 60 tons. That is why a baseline is so important… but there is no budget for laboratory examinations"*

Additionally, as the emphasis of the donor was vulnerable communities, it was possible only to work with small farmers, an approach which according to DCC limited sustainable development that should include all people (Q20 – Q21).

> Q20: *"We have a municipality that has 500 hectares of coffee and about 300 farmers, and we have one farm in another municipality that has 800 hectares. So what is more important? From the social perspective surely the 300 farmers, but to plan for development in terms of sustainability, of course you have to take into account the social, but… you must take into account everybody. But if you work only with the small (farmers), what about those farmers who make the great production, and thus great pollution?*

> Q21: *"It is the same with the protection of forest remnants, we are told we cannot include the large farmers, then what is the purpose? Protecting 20 or 30 m^2 is worth nothing. What we need is to look at the importance… It is really to protect the largest forest areas... Sure, everything is important, but as there are not (resources) for all, then what do we do? There (in the microcatchment) are small, medium and large (farmers). We never thought to work only with the largest, but working with a sample of all, but we couldn´t, because they (the donors) only focused on vulnerable communities. I'm sure what we are doing is*

very important from the social point of view, and that obviously for sustainability, but there is something else that has to do with economics, and with the environment"

Other challenges included the continuity of the strategy when the person who led this paradigm shift retires, and that people who arrive have the ability to further develop the idea with its potential (Q22).

Q22: *"So as this is not written. This is not a formula ... I see the future as far as I leave, because I do not know what will happen next. Well, there are people who are prepared, there are people studying environmental issues, there are people thinking, I know. I think in the Committee policy, it (the focus) will continue, but the important thing is not to continue writing or publishing a policy in this regard. (The important thing) is that there is someone who start generating, to join things together to build the model of coffee growing in the Valle del Cauca. Because everything is to be done, we have done something, but you know… there are always things to do. Everyone admire this, then, the real problem is not of will, is a problem of knack..."*

Insights on the catchment approach from the local community

There was a time lapse of 21 months between the first recorded semi-structured interview with the gatekeeper at DCC in Cali, and the household survey carried out in the community. This occurred for several reasons, including: i) preparation of a detailed data collection protocol; ii) delays in gaining access to DCC staff working directly in the field; iii) change of the study site after several months due to security reasons; and iv) once in the microcatchment, time invested in building trust relationships with the community. For these reasons, semi-structured interviews were not conducted at the beginning of the project with local leaders. However, the household survey carried out in the study area provided an idea of the lay understanding of the microcatchment approach.

During the planning phase of the household survey, working with the local leaders, it was found they lacked the formal microcatchment concept, and for instance, it was difficult for them to understand, why the neighbouring farm in front to theirs, will not be surveyed, or why PFP had not included these farms as beneficiaries, or why the source of supply of one of the communal water systems, did not appear on the map in which we were working. What was found working with the local leaders was confirmed with the household survey. Analyses of the survey data showed local people mainly understood a microcatchment as a headwater (74%). Others identified the microcatchment as a protected space for water conservation (17%), and some others as a place where water was taken for service provision (4%) (Figure 3-1). This was clear to those of the DCC who knew that farmers identified the microcatchment as the place where they took water for domestic consumption.

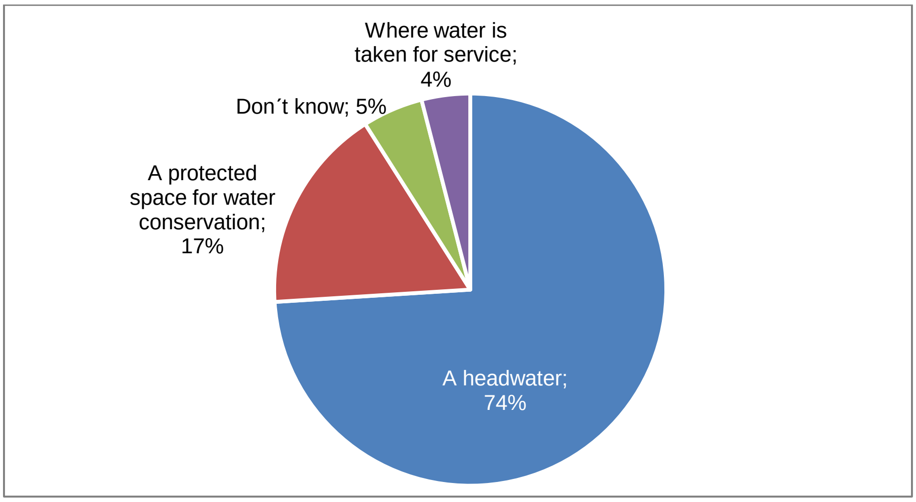


Figure 3-1 Local people concept of a microcatchment from household survey data

These results were obtained even after all the coffee farmers in the microcatchment (87% of the sample) were trained in IWRM, as part of PFP. This training included the development of several workshops and delivery of training materials, containing explanations of the catchment concept, and placed PFP and its components within the IWRM approach.

3.3.2 Stakeholders approach to IWRM - EcoHealth

Based on the initiatives developed by DCC in their jurisdiction, it could be said, their perception of a healthy catchment was a catchment where coffee growing was competitive, cultivation practices and coffee processing were developed under an ecological approach, the sources supplying water and biodiversity were protected, soil was a resource to ensure coffee productivity and it was protected. Farmers were compensated for the protection of natural resources through Payment for Environmental Services (PES). Food security was guaranteed for families, and people were educated on issues of care for nature. The coffee growing families were empowered and led sustainable development in microcatchments. The various initiatives to advance the purpose of sustainable coffee production in the context of sustainable or healthy catchments included: efficient fertilization; development, transfer, and implementation of systems for management of coffee processing by-products; strategies to improve coffee competitiveness; and provision of infrastructure, including water supply systems, sanitation, schools, and roads. Some quotes from the interviews with the gatekeeper highlight how he perceived articulation of the different initiatives (Q23 – Q27):

> Q23: *"We have been doing efforts on research and transference of technologies to reduce both water use and the possibility of pollution with organic waste (from coffee processing). A number of results are already evaluated, and have been adopted"*

> Q24: *"It's about making efficient agriculture with minimal land use, but ensuring profitability ... for example we designed seven unique fertilizer formulas for Valle del Cauca, according to soil type, looking for the most efficient way to fertilize..."*

> Q25: *"With support from CVC, we had a pilot to design PES schemes in one catchment… we are working on the coffee cultural landscape project, undertaking actions that allow flow from the local wildlife... All our areas must work under the (IWRM) concept: the extension area responsible for giving competitiveness to the coffee industry, and the social development area that provides the infrastructure: roads, schools, water supply, sanitation, capacity building…"*

> Q26: *"Because you have coffee farming, but who does coffee farming? People. And people can build community leadership… what we want is coffee communities leading the development of the catchments"*

> Q27: *"…all the results of what happens there (in the catchment with all interventions in different areas) can be attributed, must be correlated with the catchment. So that's where all the opportunities to interpret (the results) are opened. We must generate indicators of sustainability for the coffee industry, as it is so complex ... prepare for the future with a sustainability focus… then the catchment concept is being incorporated to everything we do"*

In contrast to the IWRM approach, the formal EcoHealth approach was new to DCC. However, they recognized the connection between healthy environment and healthy people, and had clear understanding that health not only depends on the physical condition of individuals, but was intimately linked to a range of social determinants (Q28).

> Q28: *"In our intervention model we have at least two things clear, and one is the food security component, and the other is that of sanitation, and one that is complementary, which is to improve productive infrastructure because that also*

pollutes. My premise is that what is happening there (in the microcatchment) with regards to our intervention model should be promoting human health"

PFP had as goal: "*to improve the living conditions of rural communities, working around water as the guiding principle in pursuing poverty alleviation and sustainable development, creating a favourable environment for life, work and the production of goods and services"*. PFP had five components: construction of facilities for pollution control; implementing gardens to promote self-production and consumption of basic nutritional products; renewal of coffee plantations to increase productivity; forest preservation around headwaters of communal water supply systems; capacity building on crosscutting issues like good agricultural practices, food security and environmental protection. The project articulated a set of interventions, which may seem scattered, but at the end would potentially contribute to improve catchment health and human health and wellbeing.

It was believed the work through microcatchments provided opportunities to achieve sustainable development of coffee communities. For example, promoting strategies like PES and be better prepared for the developments in the national regulation in relation to pollution control (Q29 – Q30).

Q29: *"We thought the work had to be focused in two ways. One, improve coffee farming in order to give all the characteristics of competitiveness, but also involve everybody in the "story" of payment for ecosystem services to supplement income and to find opportunities to work with the catchment approach, and opportunities for the sustainability of communities ..."*

Q30: *"if we decrease water pollution to the sources, necessarily that is going to be reflected downstream… That is why we do sanitation interventions and we will also implement coffee processing infrastructure, so there we must have results in BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand)"*

In relation to the linkages between catchment health and human health, data on the incidence of acute diarrhoea in rural Valle del Cauca was included in the rationale of PFP proposal to leverage international funds. It was presented as one of the problems to be addressed to achieve the aim of "*improving the living conditions of rural communities in Valle del Cauca, working around water as the guiding principle*…" However, when this PhD proposal based on the PFP proposal was discussed with DCC members, one official who participated in writing the donor proposal said diarrhoea was not a good indicator for research, because that was not an issue in the microcatchment. Therefore, the need to convince donors and the lack of accurate data about the real conditions in the study area, made DCC define the problem in proposals looking for funding around aspects they anticipated were either not important in their communities or difficult to verify. This was later supported by results from the household survey (see Chapter 4) (Q31 – Q32).

> Q31: *"Diarrhoea is not endemic in the area. You will not find it because you know that diarrhoea is already super controlled and there is a sub-register" (FRGSI-C5-2012[4],[5])*

> Q32: *"If you arrive and find a baseline that has a degree of pollution, where there is mostly an economic activity, coffee, which is not generating risk factors for the community health that for us is extremely important... Otherwise, what may fall short is the intervention model, or the levels of pollution we are generating with the productive activity (coffee production) are harmless to the community health"*

Insights on IWRM-EcoHealth from the local community

Given that most people in the community understood a microcatchment as the place where they got water for consumption, people perceived a healthy catchment depending on the possibility of obtaining good water quality to meet their needs. Analysis of the survey data resulted in three main broad perceptions of a healthy catchment: free of pollution (53%), well forested or protected (26%), or one that provides clean water (9%) (Figure 3-2).

[4] FRGSI refers to First Round Group Semi-structured interviews conducted, C5 is the stakeholder´s code and 2012 indicates the year in which the interview was conducted

5 Stakeholders´ codes are shown in Appendix A

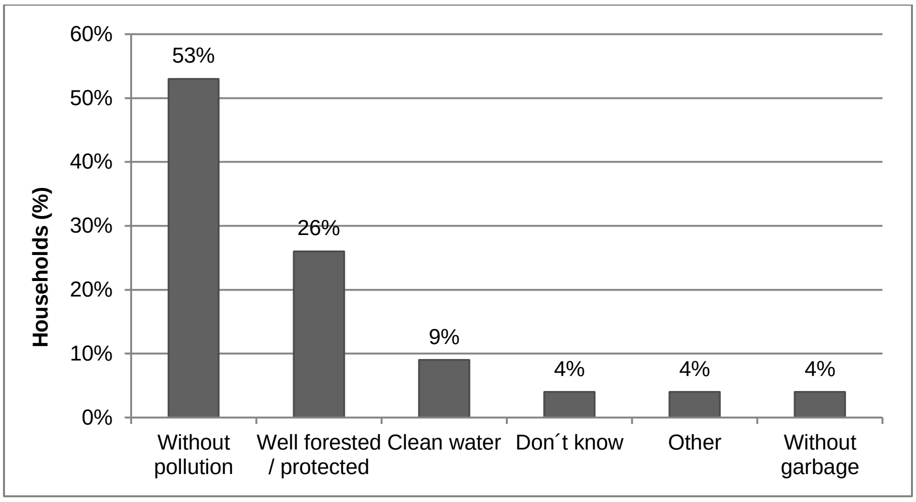


Figure 3-2 Local people perception of a healthy microcatchment from household survey data

3.3.3 Pressing issues over catchment health and human health and wellbeing

Considering the perception of a healthy catchment hold by DCC staff, which was multidimensional, involving social (e.g. empowered communities), economic (e.g. competitive coffee farming) and environmental aspects (e.g. water, forest, biodiversity), they perceived the most pressing issues at catchments in Valle del Cauca linked to water resources and competitiveness of the coffee business as factors enabling communities a good standard of living (Q33):

> Q33: *"What concerns me about catchments in Valle del Cauca is the issue of water resources… and also competitiveness of the community, of coffee production, because coffee production is losing competitiveness, is losing markets. And that (competitiveness) is a way to rescue opportunities for coffee growing communities. Not even of coffee, of communities".*

For the community in *Calabazas* microcatchment, the pressing issues they perceived in relation to the environment were: deforestation (36%), inadequate waste management (16%), use of agrochemicals (8%), water pollution (6%), and literally, the forestry company which owned commercial plantations of Eucalyptus (6%) (Figure 3-3).

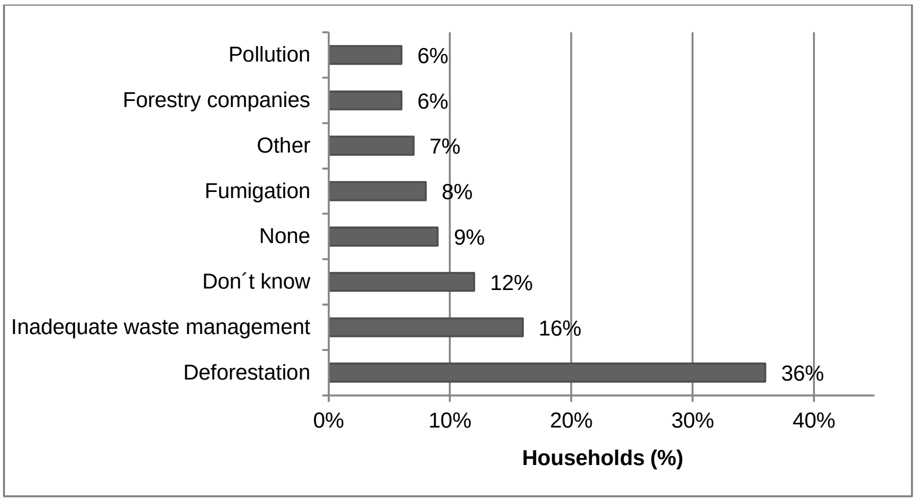


Figure 3-3 Local people perception of environmental problems from household survey data

The pressing water-related problems identified by people were: scarcity and drought (32%), and again deforestation (12%). A large number of respondents said there were no water-related problems in the region (22%), while others said they ignore which the problems were (15%) (Figure 3-4). Aspects mentioned by respondents grouped in the category "other" include: general pollution, pollution from coffee processing, poor community organization, poor maintenance, lack of resources, lack of pressure on the water supply system networks, high slopes, commercial forest plantation, and the forestry company.

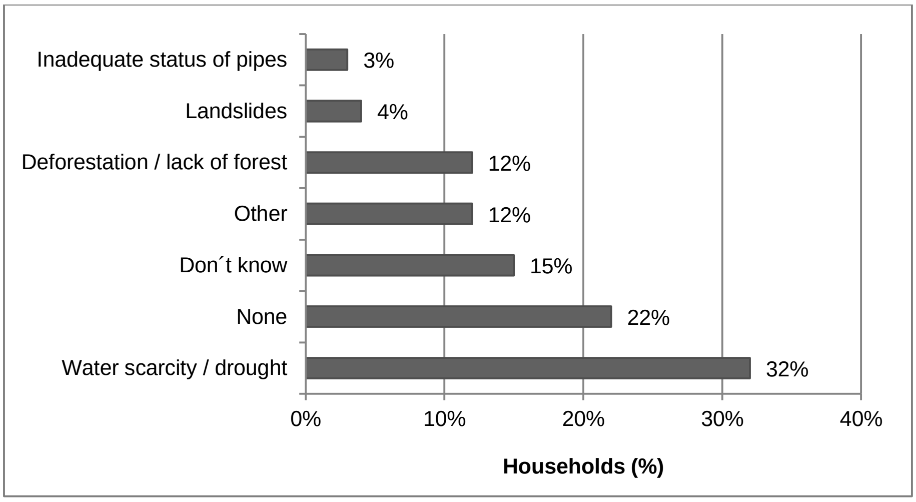


Figure 3-4 Local people perception of water problems from household survey data

Concerning to the most pressing health problems, respondents identified: flu (50%), inadequate nutrition (3%) or hygiene (3%) and diarrhoea (2%). 5% felt that there were no health problems, and several stated phrases such as “*around here people are very healthy*”. In this line, a 26% was not able to recognize any health problem (Figure 3-5). Aspects mentioned by respondents grouped as "others" include: hypertension, viruses, pollution, lack of septic tanks, herbicides, water-related diseases, and climate.

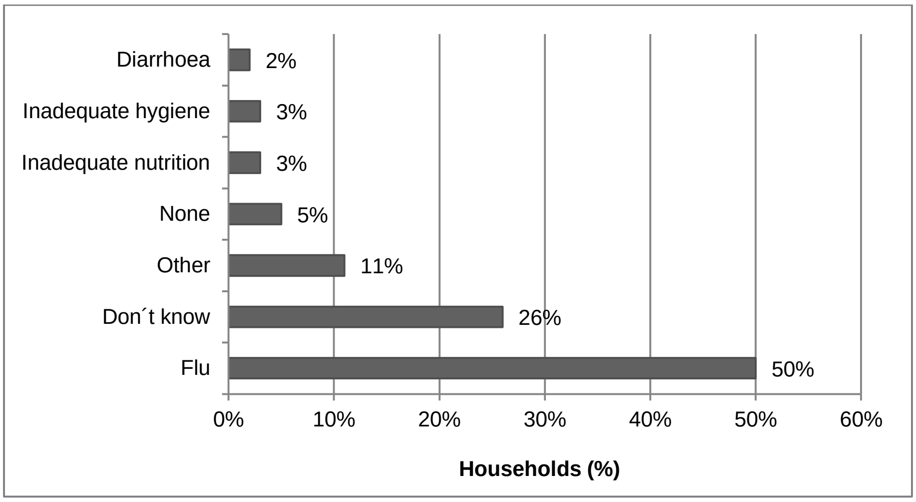


Figure 3-5 Local people perception of human health problems from household survey data

3.3.4 Factors influencing catchment and human health and wellbeing

Factors mentioned by the DCC team during individual and group interviews regarding human health and wellbeing and catchment health are shown in Figure 3-6. To represent the diverse nature of factors colours are used for the different dimensions: economic - green, environmental - blue, technical - orange, social - yellow, and institutional - fuchsia.

Fifty-five factors were derived and assigned to the dimensions as follows: environmental (16), economic (12), social (11), health and wellbeing (9), technical (5), and institutional (3). The location of factors in the dimensions is subjective and one factor could belong to multiple categories. For example, education could be considered within the social dimension or within the health and wellbeing dimension. Most factors were categorized at the microcatchment level (26), followed by farm (16), external (9), and individual (4) levels. Likewise with dimension, although the factors were located in a spatial scale, most of them have influences across scales. For example, the exchange rate was placed at the external scale, but it influences family income at farm level. In addition, depending on aggregation, some factors can be taken to a higher level. For instance, sanitation infrastructure at the farm level, could become improved sanitation coverage and placed at the microcatchment level.

DCC identified the largest number of factors (15/55) in the environmental dimension at microcatchment scale. Some of them included: natural forest cover, biodiversity, rainfall, slope, erosion, altitude, pests, and brightness. Climate was the only environmental factor mentioned at the external level, and soils at the farm level. Subsequently, DCC identified several economic factors (12/55), at all scales, especially at the farm and external levels.

Economic factors at the external scale were: cost of agrochemicals, coffee profitability, free trade, and international coffee prices. At farm scale, economic factors included: coffee productivity, farm size, family income, and household size.

DCC identified 11 social factors. At microcatchment scale: social tissue, participation, organization, violence, migration and solid waste management. At farm level, agricultural practices and the use of agrochemicals; and at the individual level, education and awareness.

Factors identified in the health and wellbeing dimension (9/55) were distributed relatively homogeneous across scales. At the catchment level, the availability of recreational spaces and the incidence of respiratory diseases, and water-related diseases were alluded. At the farm level, household habitability and food security. At the individual level, episodes of diarrhoea, respiratory infection and diet.

A smaller number of factors were identified in the technical and institutional dimensions, five and three respectively. The technical factors were: water supply and waste management infrastructure (catchment level), and sanitation infrastructure and by-products management (farm level). All institutional factors were assigned to the external level and included: incentives for coffee production, coffee price subsidies, and exchange rate.

Identification of factors by local people

Factors obtained from local people and their categorization are shown in Figure 3-7. Fifty-two factors were found and assigned to the six dimensions: social (17), environmental (16), technical (6), economic (5), health and wellbeing (5), and institutional (3). Most of these factors were linked to the microcatchment level (23), followed by the individual level (15), external level (7), and farm level (7).

The community identified a larger amount of social factors (17/52) that were located predominantly at the individual scale. At microcatchment scale, factors such as: organization, cooperation, cohesion, and water committees training were noted. At the farm scale, social factors were associated to practices: use of agrochemicals, use of water, household water treatment, and recycling. At the individual level factors including: awareness, training, knowledge, hygiene, and values such as responsibility, respect for nature, greed or neglect were raised.

Factors in the environmental dimension (16/52) were accommodated mainly at microcatchment scale. Some of them included: natural forest cover, commercial forest cover, rainfall, erosion, plagues, headwaters vulnerability, soil stability, air and water quality, and coffee processing wastewater. Global warming, climate change, and climate variability were mentioned and placed as environmental factors at the external level.

The community mentioned technical factors, placed at the microcatchment and farm levels: solid waste management facilities, status of water systems, drinking water treatment, and maintenance. At the farm level, factors were access to improved water and sanitation.

The community referred to few factors in relation to the economic and health and wellbeing dimensions, five in each. The economic factors were distributed at all levels: The economy (external), poverty (microcatchment), household income (farm), job opportunities and resources availability (individual). Health and wellbeing factors were all classified at the individual scale and included: undernourishment, flu, viral, dengue and diarrhoea.

Finally, with regards to the institutional dimension, three factors were elicited: government support, control from CVC (external level) and the forestry company (microcatchment level).

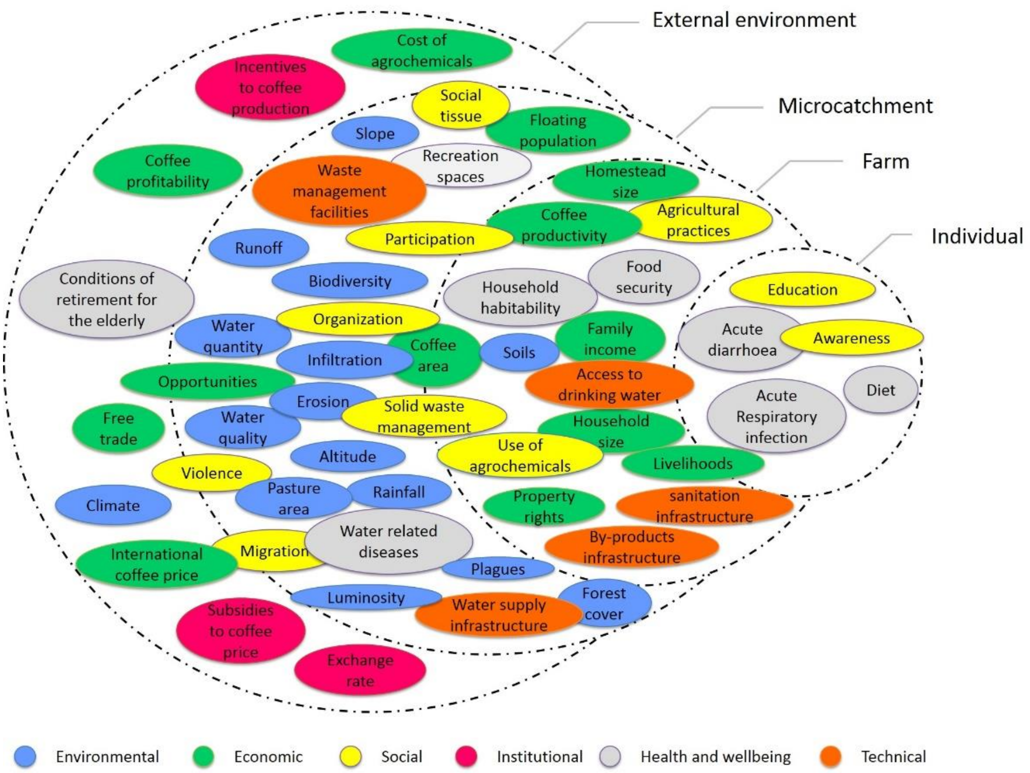


Figure 3-6 Factors elicited from DCC on catchment health and human health and wellbeing through semi-structured interviews

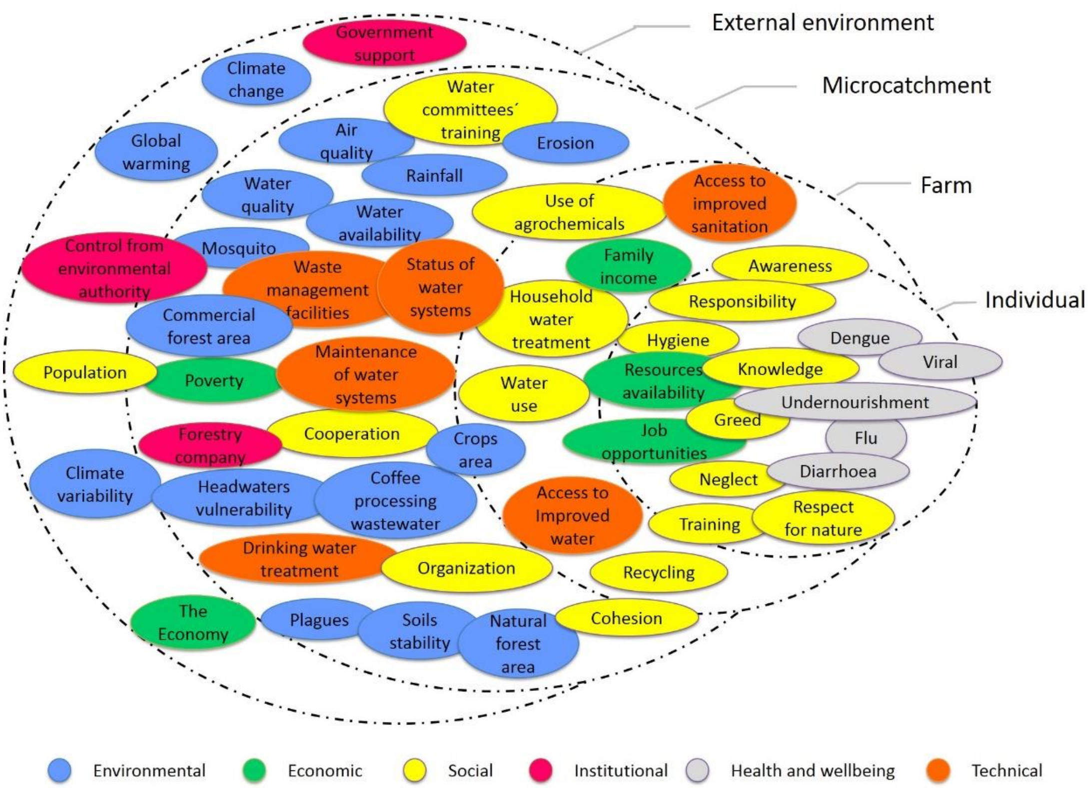
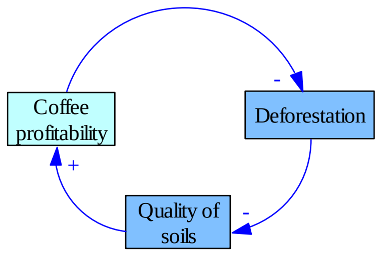
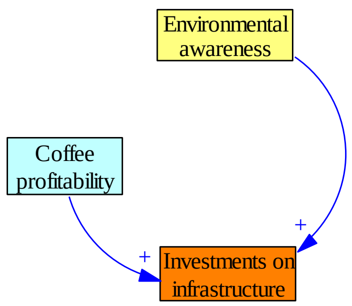


Figure 3-7 Factors elicited from local people on catchment health and human health and wellbeing through the household survey

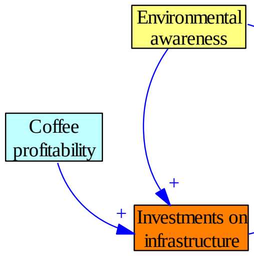
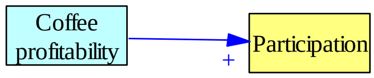
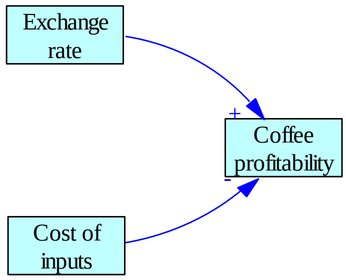
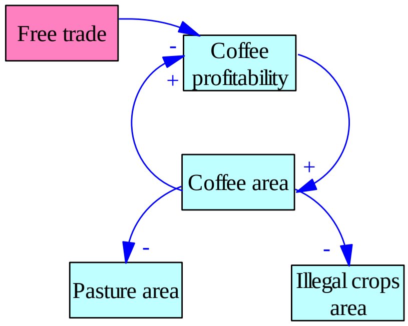
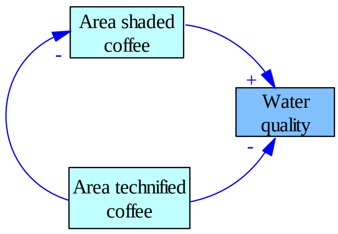
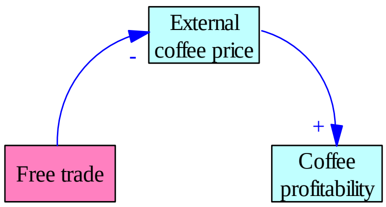
3.3.5 Structure of the preliminary model

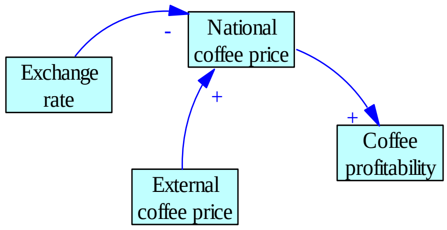
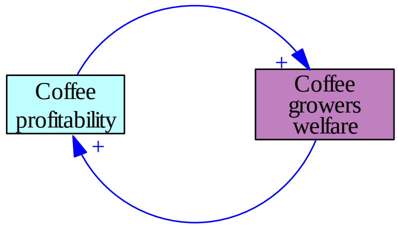
Factors elicited from the semi-structured interviews with DCC staff were connected based on relevant interviews´ fragments and analysis of documents content. Table 3-1 presents examples on how some fragments from the semi-structured interviews were used to build connections between factors (Q34 – Q41). Some of these fragments resulted in feedback loops (e.g. Q34, Q38, Q41), while others result in cause-effect relationships (e.g. Q35- Q37, Q39 - 40). To show the diverse nature of factors colours have been used to represent different dimensions in the same fashion that for diagrams in 3.3.4.

Table 3-1 Linkages between factors over catchment health and human health and wellbeing elicited through semi-structured interviews

Quote	Relationships between factors[6]
Q34: *"When there is no economic stability the first thing that is affected are the natural resources. If you start to deforest the microcatchment, if forests are not preserved, problems start to arise with soils that eventually make coffee growing slowly break down" (FRGSI-C6-2012).*	
Q35: *"We have a very strong focus on raising awareness on environmental issues. Then if they (the coffee growers) would have money, if the coffee business was good, they would build their septic tanks and would make good management of the coffee by-products. Then, when you manage to do interesting work from the social component, but if it is not accompanied by the economic resource for infrastructure, then there are problems" (FRGSI-C3-2012).*	

[6] A positive causal relationship (+) means that increase in Factor A would result in an increase in Factor B; or that a decrease in Factor A would result in decrease in Factor B.
A negative causal relationship (-) signifies that an increase in Factor A would result in a decrease in Factor B; or that decrease in Factor A would result in an increase in Factor B.

Quote	Relationships between factors[6]
Q36: *"Most coffee farmers know the way in which they affect the environment but due to financial inability to invest in the productive part of their land they cannot make decisions to change this fact" (FRISI-C1-2012).*	
Q37: *"When there is no economic stability, participation is affected. For example if they (the farmers) do not have resources, they cannot stop working to take part in community development activities" (FRGSI-C5-2012).*	
"The coffee industry is not still profitable primarily due to the cost of inputs and the revaluation. In Colombia, agricultural inputs are extremely expensive. In Brazil, Peru, Ecuador (the cost of agricultural inputs) is like 40% below" (FRISI-C1-2012).	
Q38: "*The breaking of coffee quota agreement in 89 coincided in the 1990s with the boom in drugs, when there was an offer to replace coffee with illegal crops, and started accumulation of land, speculation, and establishment of paddocks for money laundering, all added to the lack of motivation for the (coffee) price" (FRGSI-C2-2012)*	
Q39: *"The evolution of land use in the last 15 years is fundamental to understand the deterioration of water sources. It is when you take the picture 15 years ago, if coffee was under shadow that is calculated as agroforestry or secondary forests" (FRGSI-C1-2012)*	
Q40: "In 1989 roasters said: with free competition, we must release the price and depending on supply and demand we buy. That was the break of the coffee quota agreement, which guaranteed price stability over time. That destabilized because we were not prepared to deal with this model" (FRGSI-C2-2012)	

Quote	Relationships between factors[6]
Q40: *"The coffee price is not currently the international price. Today the international price is right, but not the exchange rate policy from the National bank. Since there is revaluation that is affecting us horrible"* (FRGSI-C2-2012).	
Q41: "*Coffee production is losing competitiveness… and that (competitiveness) is a way to rescue opportunities for coffee growing communities"* (FRISI-C1-2012).	

Information in Table 3-1 shows how economic factors, and in this case due to the stakeholders nature, coffee profitability, influenced by institutional and economic factors at the external scale, have impact over economic, environmental, social, technical and health and wellbeing factors at the microcatchment scale. For instance, the first row in the table presents a feedback loop showing the influence of coffee profitability, that if decreasing, increase deforestation, reducing quality of soils, losing coffee profitability. Other factors widely discussed were land use change, agriculture intensification, and participation.

DCC emphasized factors from the external environment that were drivers of health and environmental outcomes at the microcatchment level. External factors were widely discussed as the main driving forces of outcomes at smaller scales. Synthesizing, if the livelihoods were not sufficient, in this case, if coffee profitability diminished, the possibilities of health and wellbeing were reduced and thus, the chances of improving the productive factors, thus leading again to profitability.

Individual diagrams prepared from the interviews shown in Table 3-1 were connected with each other from the common elements between them (e.g. coffee profitability). Factors over catchment health and human health and wellbeing in *Calabazas* microcatchment elicited from these preliminary interviews with DCC staff are presented in Figure 3-8.

The external scale factors are represented by boxes with solid black thick lines, and the factors at the microcatchment scale are represented by boxes with solid grey lines. Factors without boxes are copies of external or internal factors reproduced in this way to avoid stretching factors over long distances that otherwise would decrease the clarity of the diagram. In this diagram, factors from the farm or individual scale are aggregated and presented at microcatchment scale. Colours differentiate factors according to dimension as in Section 3.3.4. The diagram shows the complexity and diversity of the factors affecting the issue under study, and capture the different opinions, perceptions and knowledge from DCC members. The diagram is a step forward to identification of multi-dimensional and multi-scale factors presented in 3.3.4.

The diagram helps with identifying relationships among the factors and progress towards the system´s understanding. In brief, farmers´ income emerged as a central factor. This income depended on the profitability of coffee production and conditioned that both coffee growers and the NFC had resources to invest in different aspects related to environment, health and wellbeing. On one hand, part of the business income nationwide went to NFC and was used to provide goods and services to coffee farmers: research, technology transfer, extension, improvement of productivity, and infrastructure (roads, water, sanitation, schools). Likewise, if farmers had adequate income levels they could invest in improving their living conditions (education, health, housing, sanitation, water), and in the competitiveness of their productive activities (renovation, fertilization, by-product management).

Investments from DCC and the farmers would have impact over different dimensions at the microcatchment scale. However, profitability could not be seen on isolation. Business profitability was in turn affected by a number of internal and external factors. Among the most important external factors were international coffee prices, national exchange rate policy, and the cost of inputs. An internal factor that influenced the profitability was production. At the same time, production was influenced by internal and external factors, internal factors being planted area and external factors climate variability and strategies to maintain the plantations under optimum productivity that mainly depend on FNC research, development and transfer (e.g. renewal of aged plantations).

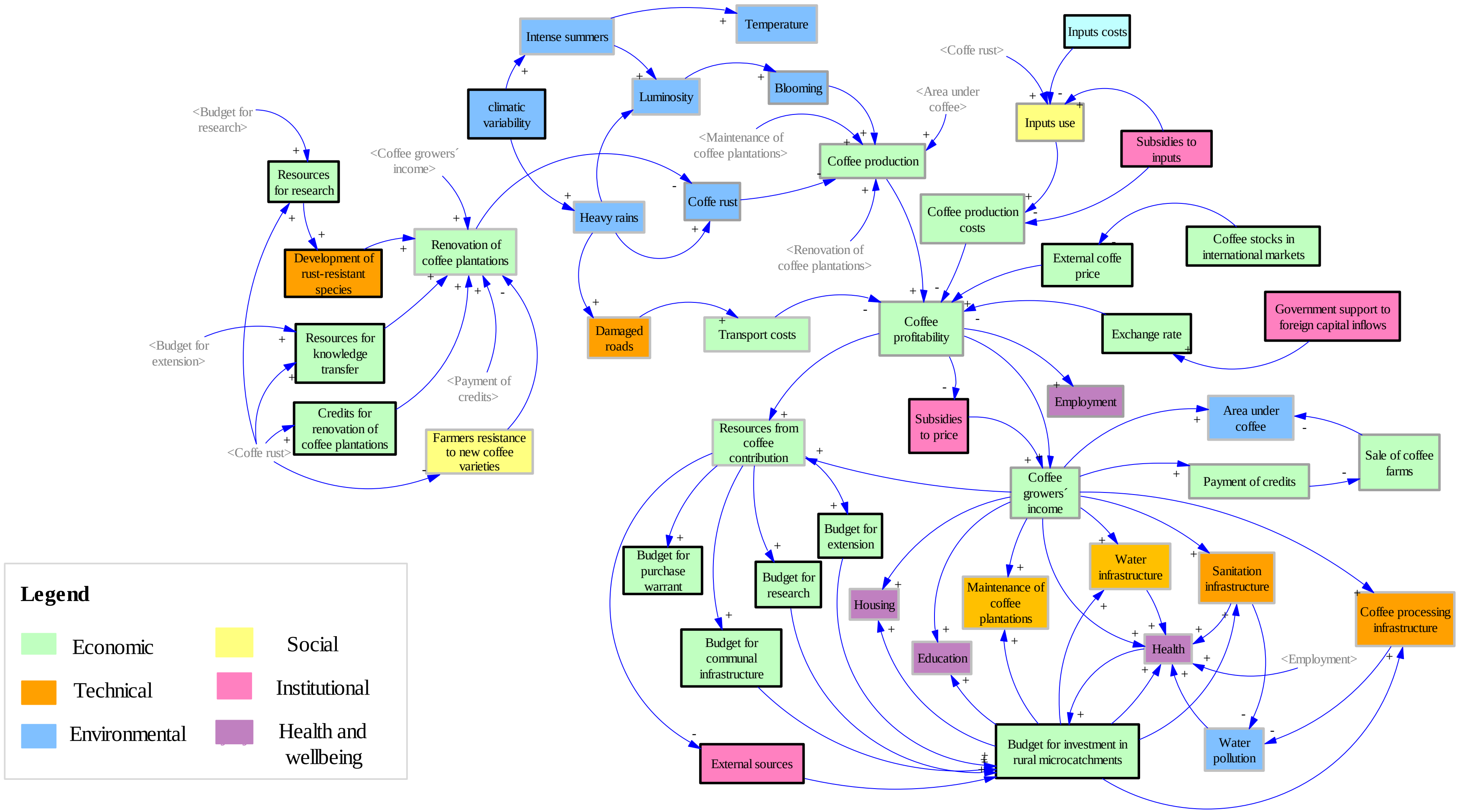


Figure 3-8 Causal diagram representing DCC knowledge on catchment health and human health and wellbeing elicited through semi-structured interviews

Insights from the local community

The gap between the completion of these semi-structured interviews with DCC staff and the activities in the field did not allow to formulate a preliminary model that incorporates community perceptions from the start. However, community perceptions obtained through the household survey provided ideas that were introduced into subsequent stages during model formulation. Among these insights are: the importance given by the community to the social and institutional aspects, in contrast to the economic-led approach of DCC. This includes considering other institutional actors, either by their presence or absence: e.g. the local government and CVC, in relation to the perception of the need for greater support for being strengthened (e.g. training, knowledge, and awareness) in the responsibilities they had due to the lack of state presence (e.g. management of water services). Another element was the need to consider the forestry company as a relevant actor, given the negative perception of the community to this stakeholder. Likewise, the importance of including farmers engaged in other productive activities, livestock keepers that despite of being few in number, were relevant in terms of land occupation. These aspects were considered in subsequent stages of the research that will be addressed in Chapters 4 and 5.

3.4 Discussion

The aim of this chapter was to explore: i) stakeholders´ approach to IWRM; ii) stakeholders´ approach to IWRM-EcoHealth; iii) stakeholders' perceptions on the pressing issues over catchment health and human health and wellbeing; iv) stakeholders´ perception of factors affecting catchment health and human health and wellbeing; and v) integration of those perceptions (mental models) in a preliminary CLD that helped to understand system's structure and provide the foundations for building a semi-quantitative SD model.

Regarding the stakeholders approach towards IWRM, the concept was adopted by the NFC, DCC in Valle del Cauca being a pilot for having the catchment as a working unit in the context of coffee production. IWRM implementation was seen as an opportunity to move towards sustainable coffee production, i.e. competitive, environmentally sound, and that enhance people´s livelihoods. It was also considered an opportunity to promote interinstitutional work and to get resources from international sources interested in the catchment approach, enabling the institution to continue working for coffee farmers´ wellbeing in rural areas.

The implementation process described by DCC offers general guidance on how to incorporate the catchment as an administrative unit: i) gain support from the general direction, ii) establish a GIS that operates with hydrological boundaries, but also with geopolitical boundaries to facilitate interagency work; iii) characterize microcatchments holistically but in relation to their particular areas of interest (e.g. coffee production in relation to catchment features); iv) redefine administrative units; v) assign staff and functions, and vi) implement pilot projects to evaluate and adjust the approach.

The organization recognized challenges in the IWRM implementation as lack of resources to monitor the impact of interventions over the behaviour of multidimensional indicators at the catchment scale. Similar concerns, for instance lack of long-term data, have been identified in China, as deficiencies on catchment health research, resulting mostly in theoretic and summarized and less practical and long-term studies (Yuan and Yang, 2011). Lack of empirical data has been also a criticism on research about IWRM implementation (Biswas, 2004; Jeffrey and Gearey, 2006; Medema *et al.*, 2008). Another challenge was the need to adjust interventions to accommodate donors´ agendas instead of local needs. This issue has been raised by authors concerned about sustainability of water and sanitation interventions in developing countries (Batterman *et al*., 2009). This creates a difficulty to advance the knowledge on how to implement IWRM with empirical information, due to the limitations associated with the sources of funding for this kind of research or development projects.

This implementation experience also offers some ideas around debates on the convenience of using the catchment as the analysis unit (Jeffrey and Gearey, 2006; Biswas, 2008; Cohen and Davidson, 2011). This experience is consistent with the arguments for pragmatic approaches (Saravanan *et al.*, 2009), or flexible approaches where the catchment is only one of a set of alternatives (Johnson *et al.*, 2001), or a policy choice (Cohen and Davidson, 2011). Nevertheless, in this case, a component of "craft" in implementing IWRM was perceived, since despite of being adopted at the organization level, much of the achievement is due to the vision, knowledge and persistence of the gatekeeper. Therefore, the continuity of the approach was not clear, given the complexity, the need for someone with the ability to integrate, with conceptual clarity, and the need of intuition above goodwill (see Q22).

Despite the fact, DCC has been working for some time with the catchment approach, beneficiary farmers were unclear about the formal concept of catchment, and associated catchments to the place where they got water for consumption, and thus the most important attribute for them was water free of pollutants. This occurred even though strategies like PFP had training components on these topics. One possible explanation for this, is the low level of formal education that Colombian farmers have. In *Calabazas*, most household heads education level was incomplete primary school (Chapter 4). In this regard, it is important that effective strategies to improve farmers´ understanding of these themes are designed, since water quality depends on decisions that are made at farm level (Winter *et al.*, 2011). However, as noted by DCC, mechanisms as PES are essential to encourage farmers to adopt production practices that minimize the negative impact on the environment, in cases like this, where the more tangible benefits are received downstream. PES are being promoted as a strategy to deal simultaneously with challenges of poverty, rural development and environmental protection (Pagiola *et al.*, 2005; Postel and Thompson, 2005).

In relation to IWRM-EcoHealth, DCC had a focus on sustainable coffee production that although was not strictly based on this approach, may fall under its general principles stated by authors such as Bunch *et al.* (2011) and Parkes *et al.* (2010). DCC approach integrated elements from the economic (profitability of coffee production), social (empowered communities leading the development of the catchment), environmental (protection of water sources and biodiversity), and human health and wellbeing dimensions (food security, sanitation, income), taking the catchment as the analysis unit.

Although EcoHealth was new to DCC, they recognized linkages between healthy environment and healthy people, and saw connections between the environment, social determinants of health and human health and wellbeing, and it was expressed in the range of interventions they undertook. In particular, PFP articulated a set of multidimensional interventions that would potentially contribute to improve human health and catchment health. Hence, the restoration of old coffee plantations would increase production, generating greater economic stability, reducing farmers’ vulnerability to different shocks, including diseases. The food security strategy also would contribute to farmers´ resilience and both strategies addressed social determinants of health. Individual sanitation systems and management of coffee processing by-products sought to reduce the impact over ecosystems, particularly water resources, from human settlements and the productive activity. Finally, these efforts were reinforced through the avoided deforestation and fencing of headwaters strategies, which could reduce risks associated to pollution of water sources used for human consumption.

DCC used the terminology of healthy catchments to apply for international aid, and project´s components suggest DCC´s healthy catchment understanding was similar to that from authors that research on agricultural catchments in Australia (Walker, 1997; Reuter, 1998; Schwenke et al., 2003; Huang, 2011). They consider within the attributes of a healthy catchment, aspects of Socio-ecological systems (SESs), resilience and provision of environmental services. These authors subscribe to the definition of healthy catchments by Walker (1997) as those in which the system is able to recover from human intervention, preserving their functions. Among the functions are: quality of water for human consumption and productive use; stream water quality to preserve biodiversity and its purposes; land to sustain productivity and income; biodiversity to sustain ecological functions; scenery to conserve aesthetic value and quality of life. Like these authors, DCC stressed productivity and profitability of productive activities, and environmental conditions to ensure provision of environmental services (De Groot *et al.*, 2002). This view is different from the concept of healthy catchments from some U.S. authors for whom catchment health is primarily linked to the quality of water sources, examined through physicochemical and biological indicators and indexes (Singh *et al.*, 1999; Aspinall and Pearson, 2000; Snyder *et al.*, 2005; Hascic and Wu, 2006). It is also different from the view of river health expressed in the Water Framework Directive (WFD) in which assessments are based on hydromorphological, physico-chemical and biological characteristics (EU, 2000; Oberdorff *et al.*, 2002; Pont *et al.*, 2007).

Concerning to the pressing problems on catchment and human health, perspectives from DCC were slightly different compared to those from the community. This can be explained because DCC context was in fact the microcatchments of the 42 municipalities in Valle del Cauca department covered by the organization. In contrast, the community perspective was linked to the context of *Calabazas* microcatchment, where they lived, got their livelihoods, benefited from what it offered and suffered from what it lacked.

Deforestation was identified by people as the most important environmental problem (36%) (Figure 3-3), and an important water problem (12%) (Figure 3-4). However, this perceived deforestation may refer to the case of *Calabazas* as an event already accomplished, since the region has been subject of a process of removing natural forest to establish crops since 1910 (Loaiza, 1995). Despite the fact that in Colombia, the natural forest area tends to decrease, officials from CVC indicated in these Andean ecosystems, what was possible to clear, has already been cleared, and remaining natural forest are preserved in areas where high slopes or soil quality did not allow other land uses. During fieldwork, natural forest was observed in riparian areas in the upper part of the microcatchment (coffee zone), while in the lower part (livestock zone), the riparian vegetation was removed. Thus, the local perception of deforestation as a pressing issue may be due to: i) changes in shaded coffee to coffee without shade seeking to increase crop yields; and ii) periodic harvest of commercial forest. The establishment of new areas of crops or livestock in areas previously occupied by forest is an additional reason, though less likely, because as previously stated, it seems that land areas where natural forest could be changed to productive uses have already been deforested long time ago.

Flu was perceived by people as the most important health issue in the microcatchment (50%) (Figure 3-5). This result could be related to the behaviour of influenza in tropical countries, where this disease occur throughout the year, causing regular outbreaks (WHO, 2014). In Colombia it has been found that different viruses associated to seasonal influenza circulate from April to December, with peaks between September and October and a minor peak in April and May (Porras -Ramírez et al., 2009). The prevalence of influenza in children from 1 to 4 is 50% (Arrieta-Flórez and Caro-Gómez, 2010). However, the most serious morbidity and mortality occur in children under 2 years of age and adults over 65 (Porras -Ramírez et al., 2009).

With regards to the identification of factors that influence catchment health and human health from the IWRM-EcoHealth perspective, DCC and the community agreed in the amount and type of factors identified in the environmental dimension. Although, community members were deeply concerned on climate-related factors, such as changing climatic conditions, extreme weather, and global warming as external factors that affect their environment and health. These issues emerged frequently maybe because they experienced the effects of extreme climate events, particularly the rainy season of 2011, which caused a severe outbreak of rust, which made it necessary to remove most of the coffee and replace plantations with resistant varieties. This led to a major economic crisis, exacerbated by other factors that had been difficult to overcome.

DCC emphasized factors from the economic dimension. From their point of view, economic factors determined the profitability of coffee production, from which the capabilities of DCC and the community of having healthy environments with people enjoying good health and wellbeing were dependent. Even though, the community also recognized economic factors such as poverty, availability of resources, and family income, they emphasized the social dimension including factors like knowledge, practices, resource use, and values. Although DCC also stressed the importance of awareness raising and capacity building, their perception was that without economic resources, these strategies were insufficient to achieve improvements.

The two groups agreed on factors related to water and sanitation infrastructure. While coffee growers mentioned the importance of coffee processing by-products management, community members referred to the need for solid waste management facilities. Community emphasis on infrastructure highlights health inequalities related to lack of resources at the household and communal levels, which demand public policy action (Ezzati *et al.*, 2005). The community also stressed the need of support from the municipal government and CVC, and identified the forestry company and its plantations as a negative factor. The frequent reference to the forestry company was a surprising result, because of the relatively small area occupied by these plantations and because they were not mentioned by DCC.

Although in this case there was no co-production in the literal sense, the disparities in perceptions and knowledge between DCC and community highlight the importance, as has been recommended by authors across fields such as environmental epidemiology (Corburn, 2003; 2007), EcoHealth (Witten *et al.*, 2000; Parkes and Panelli, 2001; Spiegel *et al.*, 2001; Charron, 2012) and SD (Van den Belt, 2004) of integrating the perspectives of professionals and communities, as both forms of knowledge are complementary.

The CLD contributed to articulate the stakeholders´ knowledge and structure the system, and was potentially a more adequate option to represent holistically catchment health and human health in *Calabazas* (e.g. Figure 3-8), compared to the use of unconnected sets of factors (e.g. Figure 3-6 and Figure 3-7). GMB methodology proved useful for taking relevant fragments from semi-structured interviews, and build connections between factors from different dimensions to represent DCC mental models.

In the CLD based on DCC mental models (Figure 3-8), external factors such as external coffee price and revaluation of the peso, among others, had great prominence. These factors determine the profitability of coffee production. In this case, coffee profitability had several connections to factors related to catchment health and human health and wellbeing. Similar reasoning is presented in catchment health studies in Australia, where farm productivity acts as a surrogate for economic and social wellbeing, and analysis of its trends is recommended in relation to environmental conditions (Schwenke *et al.*, 2003).

In the CLD, coffee production profitability also influenced land use changes. A similar logic was used by Langpap *et al.* (2008), integrating one econometric model of land use choice with models of catchment health indicators, where the net returns of productive activities determine the farmers' decisions on land use, which in turn have impact on water quality at the catchment scale. Likewise, Hascic and Wu (2006) identified economic processes as drivers of policies that lead to land use choices, that affect ecosystems. Land use change is an important socioeconomic force driving the change and degradation of watershed ecosystems, contributing to changes in hydrology, geomorphology, chemistry, and ecology (Snyder *et al.*, 2005; Hascic and Wu, 2006; Langpap *et al.*, 2008). This integrated consideration of external factors agrees with the calls to introduce external driving forces in search of better solutions to tackle health problems when aiming for sustainability (Corvalán *et al.*, 1999; Ezzati *et al.*, 2005; Batterman *et al.*, 2009).

For this study, the stakeholders´ mental database offered better information in the stage of creating a preliminary CLD than the written database as stated by Forrester (1987) and Sterman (2000). In this case, initially, the PFP proposal used to obtain resources from international aid, a component of the DCC's written database, was revised. In this proposal diarrhoea was presented as a problem to be addressed in the communities. Based on this information, diarrhoea was chosen as a key indicator of human health outcomes for the system, since IWRM-EcoHealth promoters see the study of water-related diseases in developing countries, as one of the possibilities for which the approach may be useful (Wilcox and Kueffer, 2008; Bunch *et al.*, 2011). However, subsequent interactions with DCC and the community showed diarrhoea was not a major problem in the study area. This supports the arguments from Corburn (2003) who stresses that community members claims based on experiential evidence should receive attention to focus on the relevant issues.

Based on the considerations above, the conditions in the microcatchment, make more relevant to use the IWRM-EcoHealth perspective in which human health is seen broadly, encompassing social determinants of health and wellbeing. Under this perspective, Bunch *et al*. (2011) view relations between health and water: “beyond the traditional focus on drinking water supply, sanitation, and contaminants to include livelihoods, employment, food and services provision, culture and identity, and catchments as contexts to improve the social determinants of health, promote sustainable livelihoods and overlapping goals across environmental and health disciplines”. Chapter 4 provides an overview of catchment health and human health and wellbeing in *Calabazas* in line with this premise.

3.5 Conclusions

This chapter achieves a representation of the relations between the economic, social, environmental, technical, institutional and human health and wellbeing factors at the microcatchment scale, relevant to rural microcatchments of Valle del Cauca, where coffee-growing is an important livelihood.

The Causal Loop Diagram, which incorporates aspects of different dimensions, used an integrated and systemic approach to represent the “*reciprocal interactions among ecosystems, society, and health and wellbeing”* (Bunch *et al.*, 2011). The diagram helped to capture stakeholders´ understanding to identify how different factors interact to produce outcomes at the microcatchment level. The results, obtained through a participatory process enabled comprehensively address environmental and human health and wellbeing concerns from multiple perspectives, disciplines and considering the distal causes of problems (Corvalán *et al.*, 1999; Ezzati *et al.*, 2005; Batterman *et al.*, 2009; Parkes *et al.*, 2010; Bunch *et al.*, 2011; Confalonieri and Schuster-Wallace, 2011; Charron, 2012).

This work adds to studies that have used systems thinking tools for multidimensional conceptual representations of systems to address issues such as: zoonosis (Neudoerffer *et al.*, 2005), water-related diseases (Batterman *et al*., 2009), or sanitation development (Tiberghien *et al*., 2011). The methodology goes beyond the procedure of researchers proposing factors or indicators to stakeholders to assess the "health" of an ecosystem or setting (Walker, 1997; Spiegel *et al*., 2001). In this case, the factors were elicited from the stakeholders´ knowledge and their experience in the system (Vennix, 1999; Van den Belt, 2004; Andersen *et al.*, 2007). It also adds to calls for making more explicit and transparent the initial stage of models´ formulation (Luna-Reyes and Andersen, 2003).

The CLD was the base to improve data collection instruments on key factors over system´s behaviour. Collection of primary data comprised: i) household survey, ii) drinking water survey, and iii) stream water survey. This information was intended to fill knowledge gaps over factors, where DCC lack of data. DCC had a complete information system to monitor economic factors affecting the coffee business (e.g. cultivated areas, productivity, prices), but did not monitor factors related to other dimensions. The results of the household survey and water surveys will be discussed in Chapter 4.

The diagram was the basis for starting the group modelling sessions with DCC staff to build a semi-quantitative model that relates catchment health and human health and wellbeing in *Calabazas*. Chapter 5 reports on this secondary and primary information, and shows how a large number of stakeholders from different disciplines and institutions were involved later in model formulation.

3.5.1 Limitations

This part of the study has a number of limitations. In this phase of the research, the results were based on limited interactions with a small group of people, especially the gatekeeper. This however was the key person to interview at this stage before interacting with a wider stakeholders´ base (Andersen and Richardson, 1997). Thus, the diagram is a partial representation of the system, formulated from the perspective of predominantly one DCC member, and could be more representative for Valle del Cauca than for *Calabazas*. This led to another limitation, which was not being able to perform semi-structured interviews with the community from the beginning. Failure to have the community perception earlier tried to be compensated including questions in the household survey to capture this information. However, differently from semi-structured interviews that allow to elaborate on topics, information collected through the survey questionnaire made difficult to establish dialogues to get information to elicit feedback loops. Some of these limitations sought to be overcome in subsequent stages of the research that will be reported in Chapters 4 and 5.

Chapter 4. Socioeconomic and environmental factors related to catchment health and human health and wellbeing

4.1 Introduction

There is increasing recognition of the fact that population health and wellbeing are strongly influenced by society and the environment (Corvalán *et al.*, 1999; Bunch, 2003; Hawkes and Ruel, 2006; Parkes *et al.*, 2010; Gentry-Shields and Bartram, 2013). In rural areas of developing countries poverty, agricultural intensification, land use change, pollution, and lack of infrastructure are determinants that contribute to decrease both environmental and human health.

In the context of human health, determinants could be grouped as socioeconomic or environmental; related to contacts; according to their place in a chain of causation (i.e. distal or proximal); long lasting or transitory (Ferrer *et al*., 2008). According to Ezzati *et al.* (2005), the validity of exposure indicators as predictors of hazards improves with increasing proximity to disease outcomes, but this narrow analysis prevents consideration of socioeconomic aspects, which are especially important in the developing world. In this regard, the final report from the Commission on Social Determinants of Health (CSDH) stressed aspects at different levels that influence health outcomes of individuals and populations. These factors include: housing and living conditions, access to safe water and sanitation, efficient waste management, food security and access to services such as education, healthcare, and transportation, among others (Kjellstrom *et al.*, 2007; CSDH, 2008; Marmot *et al.*, 2008; Bambra *et al.*, 2010).

Concerning to environmental determinants, agricultural intensification, land use change and deforestation are considered causes of shifts in infectious disease patterns, facilitating the interaction between pathogens, vectors and hosts, increasing disease rates (Patz *et al*., 2004; Myers and Patz, 2009). In agricultural catchments, pollution from pathogens is one of the most significant impacts over freshwater (Gomiero *et al.*, 2011). Rural watersheds present both point and non-point sources of microbial pollution and at the same time, they provide water for multiple purposes including drinking water (Sinclair *et al*., 2009). One of the causes of diffuse pollution is livestock intensification, which generates runoff from rangelands with substantial loads of pathogens (Patz *et al.*, 2004). Point microbial pollution is caused by continuous discharges from pipes and outfalls from individual and collective sanitation systems (Sinclair *et al.*, 2009). These pollution sources associated to land use and agricultural activities lead to water quality deterioration from upstream to downstream areas (Bartram and Ballance, 1996; Chapman *et al.*, 1996). On the other hand, seasonal variations in temperature, precipitation, dilution, evaporation, suspension, settling, volatilization, gas exchange, adsorption/desorption also produce changes in water quality (Bartram and Ballance, 1996; Leite *et al.*, 2007; Zhang *et al.*, 2009). In particular, higher microbial contamination of water sources commonly occurs in rainy season, associated with faecal contamination in the surrounding environment flushed to water sources due to increased runoff (Levy *et al.*, 2009; Strauch and Almedom, 2011).

Pollution from both point and non-point sources can be easily incorporated to surface waters used for human consumption (Patz *et al.*, 2004; Sinclair *et al.*, 2009), contributing with pathogen bacteria, viruses, and protozoa which are agents of water related diseases such as diarrhoea (Casellas *et al.*, 2012). This situation is exacerbated due to the low coverage of improved water sources in rural areas. Many piped water systems in developing countries are intermittent or do not deliver safe water (Bartram and Cairncross, 2010). Despite the fact, it is accepted that the relationship between the level of pathogenic contamination and the risk of disease depends on several factors (Eisenberg *et al.*, 2007; Batterman *et al.*, 2009; Bartram and Cairncross, 2010), drinking-water is one of the main routes for pathogens transmission (WHO, 2012b), and together with access and quantity, water quality is crucial to achieve positive health outcomes (Bartram and Cairncross, 2010).

Diarrhoea remains a major concern affecting the poor and vulnerable, particularly in developing countries (Tumwine *et al.*, 2002; Wright *et al.*, 2004; Aremu *et al.*, 2011; Khan *et al.*, 2013). Around four billion diarrhoea cases and 2.2 million deaths occurred per year around the world (Tumwine *et al.*, 2002; Bbaale, 2011; Casellas *et al.*, 2012). In the last decades, diarrhoea mortality has markedly reduced. This reduction is mainly due to general improvements in nutritional status, access to medical care, water and sanitation, vaccine coverage, oral rehydration therapy, and increased understanding of pathogenesis (Thapar and Sanderson, 2004; Ferrer *et al.*, 2008; Markovitz *et al.*, 2012). However, morbidity remains a problem, and the population most affected are children under 5 years old (Ferrer *et al.*, 2008; Sartorius *et al.*, 2010; Markovitz *et al.*, 2012). In

Colombia, it is estimated that each year about 1.5 million episodes occur, with between 60,000 and 90,000 hospitalizations (De la Hoz *et al.*, 2010).

There is a complex web of disease determinants that demands holistic understanding, incorporating different dimensions and disciplines (Ezzati *et al.*, 2005; Marmot *et al.*, 2008). One conceptual approach that promotes addressing the relationships between environment, social determinants of health, human health and wellbeing is IWRM-EcoHealth (Parkes *et al.*, 2010; Bunch *et al.*, 2011). This approach advocates for the catchment as the effective unit to link water and health management, allowing consideration of water quality, quantity, and ecosystem services determinants of human health and wellbeing. Bunch *et al.* (2011) argue this integration would be useful to: i) address the problem of water and infectious diseases, and ii) enhance sustainable livelihoods in agricultural economies dependent on water. They conclude that inequities increase morbidity and mortality, and watershed management has the potential to decrease inequities, and provide an ecosystem-based context to improve the social determinants of health.

Based on the IWRM-EcoHealth premises, the objectives of this chapter are:

i. To explore the behaviour of selected socioeconomic factors, or social determinants of human health and wellbeing in *Calabazas* microcatchment.
ii. To explore the behaviour of selected environmental determinants of catchment health and human health and wellbeing (stream water quality and drinking water quality):
    - To test whether water quality deteriorates from upstream to downstream as a result of anthropogenic influences.
    - To test whether water quality is worse in the rainy season than in the dry season because of increased mobilisation of pollutants.
iii. To explore human health outcomes related to the analysed socioeconomic and environmental determinants studied, using diarrhoea prevalence as an indicator.

The next section describes the methodology used to address the above mentioned objectives. Then, results are presented as: i) social determinants of health; ii) stream water quality, iii) drinking water quality, and iv) health outcomes. A discussion following the same structure of the results section is included. Finally, conclusions are stated, summarizing key findings.

4.2 Methodology

This section describes the methods used to collect information on selected socioeconomic and environmental determinants related to catchment health and human health and wellbeing in *Calabazas*. Diarrhoea prevalence was selected as an indicator of human health outcomes. The methods used, which are described below, were: i) household survey; ii) stream water survey, iii) semi-structured interviews with water managers and inspections to communal water systems, and iv) drinking water survey.

4.2.1 Household survey

Local leaders were identified using a snowball sampling approach (Robson, 2011), with help from the social worker from the Departmental Committee of Coffee Growers (DCC) responsible for the microcatchment. These leaders were contacted in advance to discuss the research, detailing the steps, data collection strategies, the information to be delivered to them from the investigation, and to request consent to research in their community.

The household survey was intended to collect information on: demography, education, employment, livelihoods, access to water, sanitation, solid waste management, animal husbandry, access to health care, perceptions and cases of diarrhoea, among others. Five local leaders were trained as enumerators. The training was delivered in three different places to facilitate participation, since the scatter of the area made it difficult to bring them together. Three enumerators were recruited for the south side of the microcatchment and two for the north side. The training comprised two sessions.

In the first sessions (January 2013), overviews of the research and the household survey were revised. Questions in the form were checked and explained. Relevance of the questions, wording, understanding of different terms, and aspects of informed consent, and bias were discussed. A practical example was developed to check the enumerators´ understanding on the survey and the procedures to fill the questionnaire, and to correct mistakes and provide clarifications. Enumerators received questionnaires to practice and a glossary explaining terms (Figure 4-1).

Figure 4-1 Enumerators' training

During the first training sessions, the population in the study area was established by triangulation of three information sources: i) database of coffee farms and their owners provided by DCC, ii) distribution network maps for the communal water supply systems; and iii) mapping exercises carried out with the enumerators to complete missing information or to clear records of empty houses, or plots without houses. Identification of the water sources for each household in the microcatchment was also an outcome of these sessions.

Between the first and second training sessions, a map was prepared from secondary data including: the microcatchment drainage network, land use for the most recent available year (2008), and farm location from a database provided by DCC. Livestock farms were initially placed by hand on the map by community members. Later, some of these farms were geo-referenced using a Global Positioning System (GPS) (Garmin GPS map 60CSX). The microcatchment map was divided into smaller drainage areas (33 areas) and for each resultant drainage area, the number of households being supplied by each water system was established (Figure 4-2).

The sample for the household survey was selected as 50% of the households in each drainage area, taking proportionally the number of houses belonging to each water supply alternative. This approach could potentially allow establish relations between information gathered with the household survey, the stream water survey (4.2.2) and drinking water survey (4.2.4).

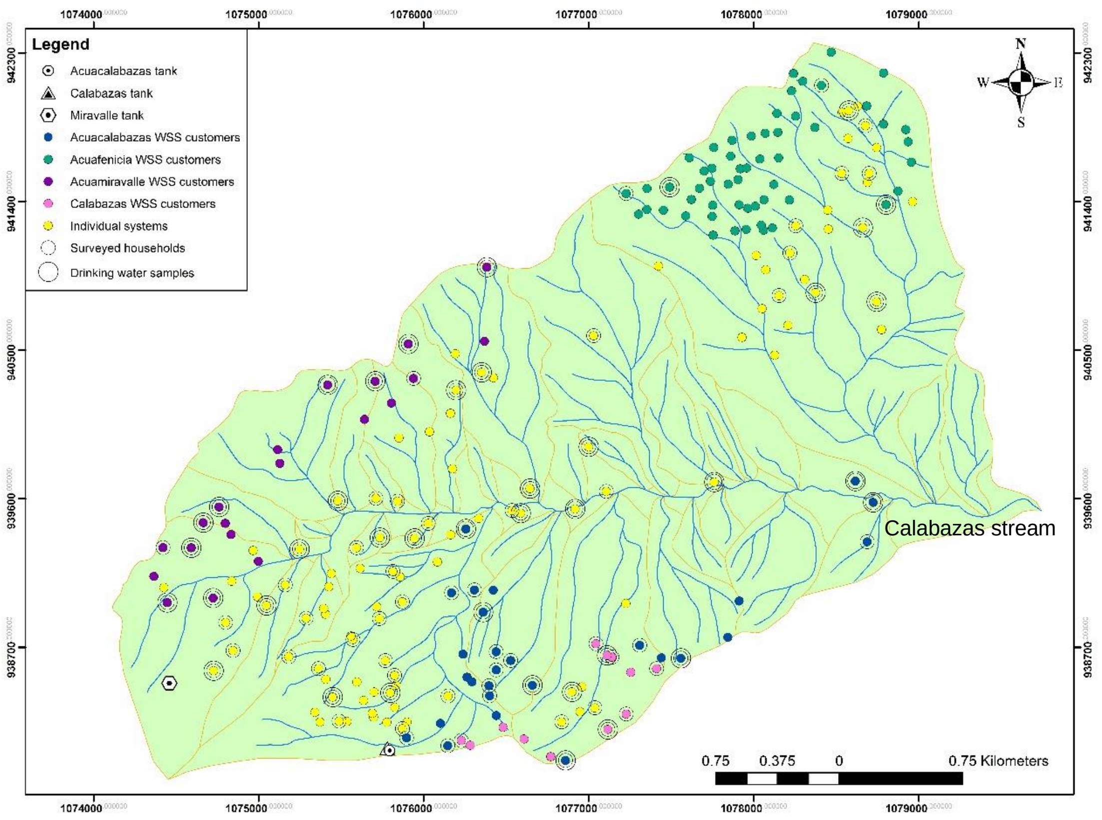


Figure 4-2 Sample frame: houses according to drainage area and water supply system

The questionnaire was reviewed, checked and printed (Appendix B) and a list of people to interview was prepared for each of the enumerators. An additional list of houses available for replacement, in case of potential problems with houses in the main list, was provided explaining the criteria for replacement (i.e. drainage area and water supply system).

The second training sessions (February 2013) involved review of minor modifications to the questionnaire, checking the filled forms enumerators used to practice, provide clarifications, and delivering materials and the lists with the people to interview.

Data collection for the household survey took place mostly from February 8th to February 25th 2013. The questionnaires were administered through face-to-face interviews. Household members more than 18 years old were targeted as respondents. Enumerators interviewed the household head and his wife / her husband where possible, with the understanding that women provided more accurate information on aspects such as: disease prevalence, and water management at home; while men were more aware of the type and scale of productive activities. During this time, the study area was visited twice a week to check and collect filled forms. Additional surveys took place from March 9th to March 13th 2013, due to an interruption in the data collection activities because of a coffee growers´ national strike. Ten more surveys were carried out from April 15th to April 18th 2013 to achieve 100 filled questionnaires. Data from the questionnaires were transferred to an Excel 2010 database. Tables and charts were prepared to display the behaviour of the values of variables studied.

4.2.2 Stream water survey

The tributary regions to *Calabazas*[7] stream shown in Figure 4-2 were characterized in terms of area and percentage of land uses as an input to select sampling monitoring points. A transect walk was carried out on February 9th 2013, accompanied by community leaders, and colleagues from Universidad del Valle (Figure 4-3).

Figure 4-3 Transect walk along *Calabazas* stream

This walk was intended to: i) verify information on land uses from secondary sources; ii) observe wastewater discharges; and iii) identify potential sources of diffuse pollution: e.g. waste handling areas, agricultural land, types of crops grown, status of

[7] *Calabazas* is the name of the microcatchment, its main stream, one of the villages, and one of the communal water supply systems.

the riparian vegetation, presence of animal grazing or kept in intensive-use areas, visible changes in water quality. Notes were taken during the walk and transferred to worksheets in Word 2010 as descriptive data following the activity.

Seven points of interest regarding potential changes in stream water quality associated with land use, wastewater discharges, and confluences of tributary water bodies were identified. Water quality samples were collected at these sites, in rainy and dry season, matching with the periods of the drinking water survey (see 4.2.4). Monitoring stations were geo-referenced with the GPS. Four sampling sites were chosen to capture changes in water quality along the length of the main stream; and it was thought that three sampling sites would be useful to identify the impact of potential differences over water quality associated to land use (Figure 4-4). However, since this was a mixed catchment in which the streams flow from coffee areas above 1300 m to grazing areas below 1300 m, only the results regarding the four sites capturing changes along the stream length are reported here. The results from the three sites monitoring tributary streams to *Calabazas* were discarded, because these streams were not different regarding land uses in afferent zones or water quality.

Figure 4-4 shows the location of sampling sites in the stream and Figure 4-5 shows sampling sites in relation to the stream profile.

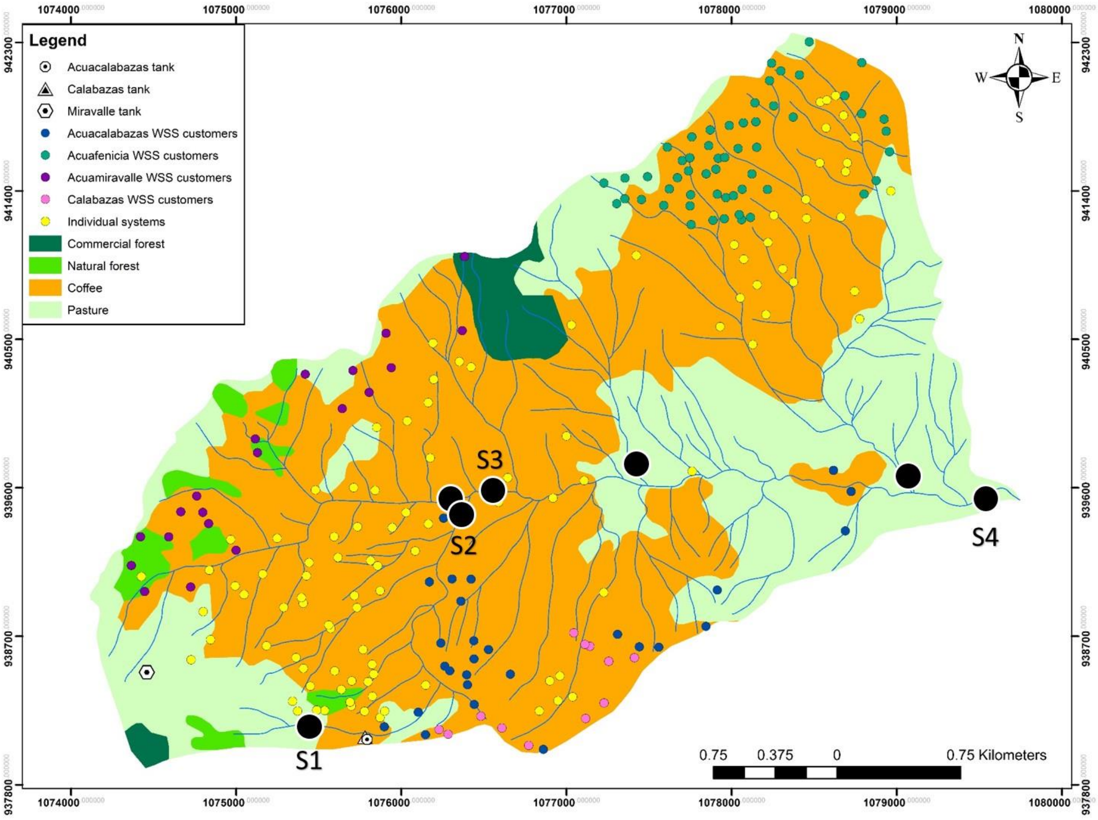


Figure 4-4 Location of sampling points for the stream water survey

The sampling points are represented in the map with the black circles (seven). The selected sampling points to report water quality in the stream (four) are those identified with the letter S and a number from 1 to 4.

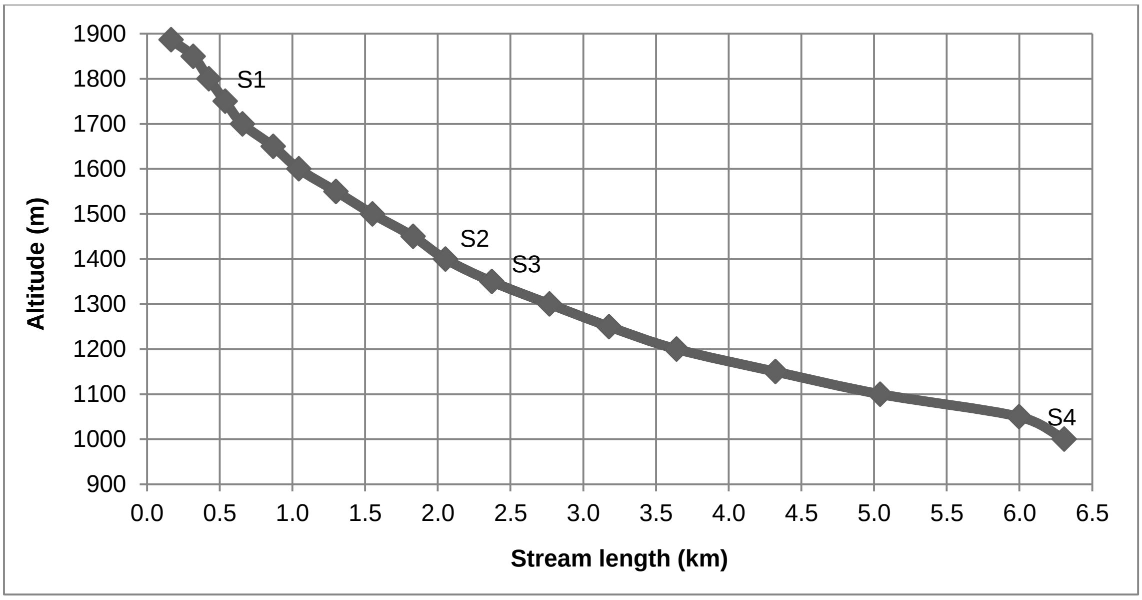


Figure 4-5 Location of sampling sites in relation to the stream profile

The brief description of the four sampling stations selected to represent the behaviour of water quality in the main stream, identified as S1, S2, S3, and S4 is as follows:

- S1: Located down gradient from a headwater spring to represent background water quality
- S2: Located after the stream passed an area of 153 Ha, 72% under coffee, 5% under natural forest, and 23% under grazing lands. There were 45 homesteads.
- S3: Located after the confluence of the two upper branches of the stream. It drained 439 Ha, distributed on 63% coffee, 28% grazing lands, 8% natural forests and 1% commercial forest, and comprised 90 Households.
- S4: Located at the catchment outlet, just before the confluence of the stream and *Piedras* river. It represented the aggregated effect of land uses and people in the area. There were approximately 250 households in 1,388 Ha. Land uses were 63% coffee, 32% grazing lands, 2% commercial forest and 3% natural forest. It captured the influence of livestock farms.

A summary of land use values, given as percentages of coffee, livestock, natural and commercial forest, according to sampling sites (S1 - S4) is presented in Table 4-1. Values in Table 4-1 were estimated from cartography available for the area (Cafeteros-Valle, 2012; CVC, 2012).

Table 4-1 Land uses and number of residences upstream of each sampling site

Site	S1	S2	S3	S4
Coffee (%)	0	72	63	63
Livestock (%)	0	23	28	32
Natural forest (%)	100	5	8	3
Commercial forest (%)	0	0	1	2
Homesteads (number)	0	45	90	250
Area (Ha)	1	153	439	1,388

Water samples were collected at the selected stations together with discharge measurements (Figure 4-6). Sampling was always carried out at the same time of the day, i.e., early morning to early afternoon. In situ measurements were conducted for: Flow, pH, Temperature, and Conductivity. Samples were taken to a laboratory for analysis of Total Suspended Solids (TSS), Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD). These variables are the minimum suggested by Chapman *et al.* (1996) and Bartram and Ballance (1996) to undertake a water survey with a simple level of complexity that provides an assessment of the overall water quality. Samples were also taken and analysed for Thermotolerant Coliforms (TTC) to explore microbial water quality in the stream. Analysis for TTC were carried out in the laboratory.

Water discharge was estimated in situ by measuring the cross-sectional area of the stream at each sampling point, and using a current meter (Turbo Flow ERDCO) to determine the average velocity in the cross-section (Bartram and Ballance, 1996). Depending on the cross section width, the depth at one or more verticals was measured and the mean velocity obtained at 60% of water column (Leite *et al.*, 2007).

Figure 4-6 Stream water survey
(a) headwaters; (b) catchment outlet

Temperature, Conductivity and pH were determined in situ with a multi-parameter tester (HI 98129). Discrete samples were taken at each monitoring point for: TTC, TSS, DO, and BOD. Samples were collected, preserved if required, kept on ice, and transported ensuring a temperature less than 4˚C to a laboratory located two and a half hours drive from the last sampling station. All samples were analysed within 24 hours of collection, following APHA methods (APHA, 2005). Sampling and analytical procedures for each parameter are summarised in Table 4-2.

Laboratory analysis for rainy season were carried out by BOD Engineering. Several circumstances forced to change the laboratory and the method to analyse TTC from the rainy season (Most Probable Number) to the dry season (Membrane Filtration). Laboratory analysis for dry season were carried by Cinara. That is the reason for which in Table 4-2, the two alternatives appear as the analytical method used for the TTC parameter.

Table 4-2 Sampling and analytical methods for the stream water survey

Parameter	Units	Container	Preservation	Analytical method
Thermotolerant Coliforms (TTC)	MPN/100ml CFU/100 ml	Sterile glass bottle	None	Multiple tube fermentation (rainy season) Membrane filtration (dry season)
Total Suspended Solids (TSS)	mg/l	Polypropylene bottle	None	Soxhlet extraction with 5520D
Biochemical Oxygen Demand (BOD)	mg/l	Polypropylene bottle	None	5-day incubation, 20◦C
Dissolved Oxygen (DO)	mg/l	Air-tight bottle, filled to overflowing and stoppered	Chemical reagents	Winkler method

In situ results were recorded immediately in designed forms (Appendix C). Results from field and laboratory operations were stored in an Excel 2010 database. Data were analysed using Excel and the R software 2.15.2. Descriptive statistics for each parameter in relation to their temporal (rainy and dry season), and spatial behaviour (between stations), were computed. For each parameter:

- Kruskal-Wallis or ANOVA tests were used to compare medians or means between the four sampling points, in rainy and dry season.
- Appropriate tests, according to the dataset distribution (Tukey, or Mann-Whitney) were used to compare between pairs of sampling points, for both dry season and rainy season
- Mann-Whitney test was performed to identify statistical differences at each sampling point between dry and rainy season.

4.2.3 Semi–structured interviews with water managers and sanitary inspections

Leaders of the existing communal water supply systems were identified using a snowball sampling approach, starting with managers contacted through the DCC´s social worker. Four semi-structured interviews were carried out with managers from the four communal systems in the microcatchment. The interviews addressed issues of history, evolution, organization, compliance with legal requirements, staff, communication, participation, institutional support, Operation and Maintenance (O&M), commercial and financial aspects, perceptions regarding water quality and the environment, challenges, and community participation (Appendix D).

Sanitary inspection formats were designed taking into account the most common water infrastructure identified (Appendix E). Inspections were carried out with representatives from the water boards and/or systems´ caretakers (Figure 4-7). One inspection was carried for each system, except for Acuafenicia, where leaders did not accept to take part in the research. Information was collected through observations focused on the infrastructure, status, and potential risks to water quality (WHO, 2012b).

Figure 4-7 Sanitary inspections to communal infrastructure
(a) break-pressure chamber; (b) grit chamber

Notes were taken during the semi-structured interviews and inspections and were transferred to Word 2010 as descriptive data on the observed events. The collected information was analysed according to themes and relevance to the research objectives. In addition, these interviews and inspections helped to shape the logistics for the drinking water survey.

4.2.4 Drinking water survey

The drinking water survey comprised collection of water samples to establish microbial water quality in communal systems, households connected to communal systems, and households with individual systems. The microcatchment population was established as discussed in Section 4.2.1. The sample for the drinking water survey was 25% of the households in each drainage area, taking proportionally the number of houses belonging to each of the water supply alternatives: Acuacalabazas, Calabazas, Acuamiravalle, Acuafenicia and individual systems. This was possible, except for Acuafenicia, where users and water managers rejected participating in the research.

Pilots were conducted in the south (12th of March 2013) and north side (14th of March 2013) of the microcatchment. Pilots allowed organizing logistics. Two people were trained in each side to collect samples. Thus, each monitoring day, three people including the student, collected samples simultaneously at selected points across the whole microcatchment to adhere to time restrictions from the methodology (time from collection to processing the samples of around four hours).

Four monitoring campaigns were carried out in the rainy season (18th March – 2nd May 2013) and four in the dry season (9th July – 14th August 2014). Each campaign comprised one day taking samples in the south side of the microcatchment and one day in the north side. In average 25 samples were taken each day, including households, communal storage tanks and schools, in different areas, with a diversity of water supply alternatives, and the communal storage tanks (Figure 4-8). To the extent of the possibilities, the same houses were sampled each monitoring day.

Figure 4-8 Sample collection for the drinking water survey
(a) communal infrastructure - storage tank; (b) household infrastructure - storage tank

Water analyses were carried out using two DelAgua Portable water testing kits following the manufacturer´s procedures (Oxfam-DelAgua, 2012). Samples were analysed for the parameters suggested by WHO (2012a): TTC, pH, Turbidity, and residual chlorine in the case of one of the systems that had chlorination. Samples were analysed in situ for Turbidity, pH and Chlorine (if appropriate). Turbidity was measured using a Jackson Tube (Figure 4-9 – a). pH was measured with the tablet count method using phenol red tablets and were checked at laboratory with a portable pH-meter (HI-98103). Chlorine residual was measured with the DPD tablets method. Samples for microbial analysis were stored in sterile polypropylene containers of 125 ml, reserved in polystyrene coolers with ice, and analysed within 4 hours from collection, with the membrane filtration method in both rainy and dry season. Each monitoring day, duplicates were analysed for seven randomly selected water samples (Figure 4-9 – b).

Figure 4-9 Drinking water quality analysis
(a) Turbidity (in-situ); (b) TTC (laboratory)

Results were recorded in designed forms (Appendix F). In the sampled households, people were asked about diarrhoea cases in any of the family members, in the previous 15 days. This information was recorded in the same form and transferred to the Excel database.

Descriptive statistics were computed to characterize each water supply alternative in relation to the studied parameters and season. Data on pH and Turbidity were generally within the range of safe water and showed low variability. The samples never had residual chlorine. Therefore, only data on microbial quality (TTC) were statistically analysed and are reported here. For each alternative of supply, the dataset distribution was established according to season (Shapiro-Wilk) and between seasons (Levene or Mann-Whitney). The Kruskal-Wallis test was used to compare communal systems without disinfection for each season. The Mann-Whitney test was used to establish if collective systems without disinfection, grouped as improved, were different from individual systems, grouped as unimproved, for rainy season and dry season, according to criteria by WHO (2012b). For the new categories, the percentage of samples in a given TTC level was established. Finally, descriptive statistics were used to identify changes on TTC levels between communal storage tanks and households for both dry and rainy season. Descriptive statistics were computed in Excel and statistical tests were performed in R 2.15.2.

4.3 Results

The following sections present results on the socioeconomic and environmental determinants of catchment health of human health and wellbeing in *Calabazas* microcatchment. First, results on the socioeconomic factors as social determinants of health are presented. Second, environmental factors as stream and drinking water quality are described. Finally, health outcomes focused on diarrhoea disease are examined.

4.3.1 Social determinants of health

The household survey yielded information on socioeconomic factors, social determinants, or factors that have been associated to human health, and wellbeing and to diarrhoea prevalence: education, employment, income, housing conditions, water, sanitation, transport, and health care infrastructure. The situation regarding each of these issues in the microcatchment is described below:

Demographic aspects

Based on the survey results, for 2013, the microcatchment population was estimated to have 850 inhabitants, 40% were women, and 60% men. For each 151 men there were 100 women; and for each 100 fertile women (15 – 49 years old), there were 18 children. The population under 15 years was 20%, and older than 65 years was 12%. 64% of the elderly were men. In 7% of the households, there were people above 80 years. The ratio of infants younger than 5 to elderly people aged 60 and older was 1:6.

Figure 4-10 includes the population pyramid for the surveyed sample. It shows that only 40% of the inhabitants were under 30 years, and the greatest male population was in the fringe 15 – 19 years, and for female between 10 – 14 years.

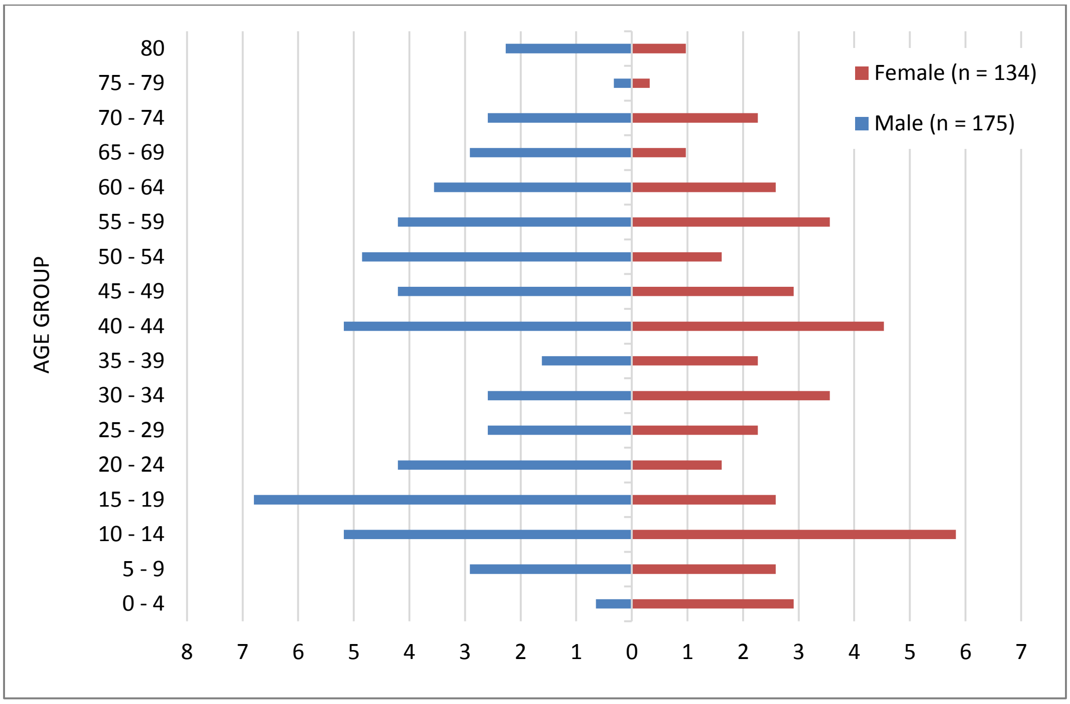


Figure 4-10 Population pyramid for *Calabazas*

The average household size was three and 13% of households had at least one child under 5 years old. 12% were single-person households. The 10% of households with more than six people were composed of families with four children or extended families (Figure 4-11).

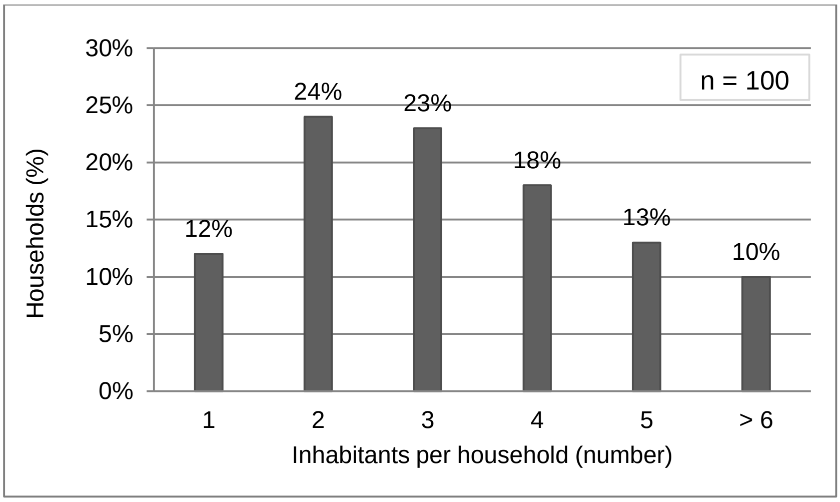


Figure 4-11 Household size

Education

There were six schools serving the villages. These schools were part of networks with two bigger educational institutions in the districts of *Fenicia* and *Portugal de Piedras*.

When the students finished primary school, the “Pos rural primary” program, provided six to nine grade of secondary school in institutions in nearby villages. The schools in the districts, offered up to 11 grade. In addition, all the children that attended school had a subsidy to cover transportation costs, paid by the local government.

Figure 4-12 shows school attendance, understood as the school-age population that was attending school at the time of the survey, regardless of grade level (UN, 2013). School attendance declined as youth get older, from 100% coverage for children enrolled in primary to 22% for the young between 18 to 24 years. 57% of those in the latter segment, who did not study, completed basic secondary, while 43% had different levels of incomplete basic education.

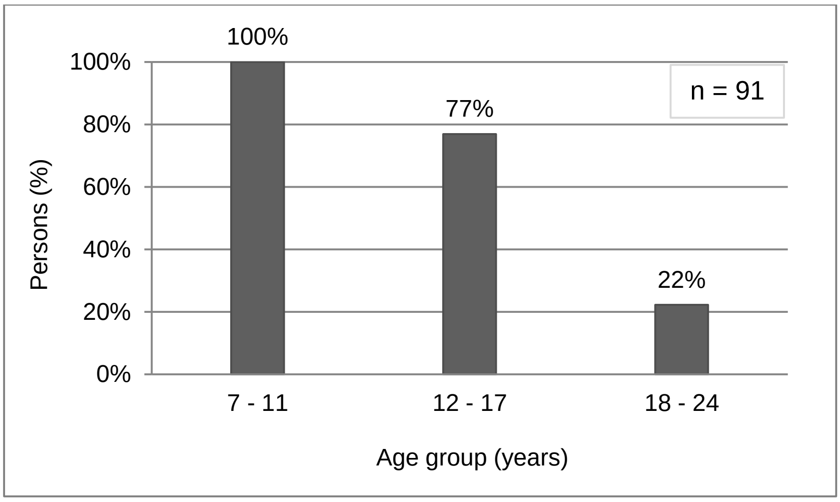


Figure 4-12 School attendance

While there was universal primary education and reasonable coverage of high school, limitations in access and quality existed. Access to schools was difficult due to the scattering of farms and steep terrain that represented walking long distances to attend schools. Some children walked up to one hour from their homes to the main road, from which they were collected by the subsidized transport. All families sending children to the schools using the subsidized transport contributed to transport costs on $1 USD per children per day. This value was a proportion of the income of a poor family in the area, which became an access barrier. Regarding quality, there was lack of teachers, insufficient training for the current teachers, poor and obsolete infrastructure, computers and bibliographic material (Riofrio, 2012).

People older than 15 years without any education were 14%. Within this 14%, 33% were adults over the age of 60. Only 16% of the population had completed secondary school, and the majority had incomplete primary school (32%). 16% of mothers did not have any school education and only 12% completed secondary school. The trend was similar for household heads, except that compared with mothers, men had greater proportion of incomplete primary school (45% - 36%), and less complete secondary school (5% - 12%) (Figure 4-13). The average school years for the population between 15 and 24 years was 8.9. Household heads had an average of 4.4 years of education and mothers an average of 5.1 years.

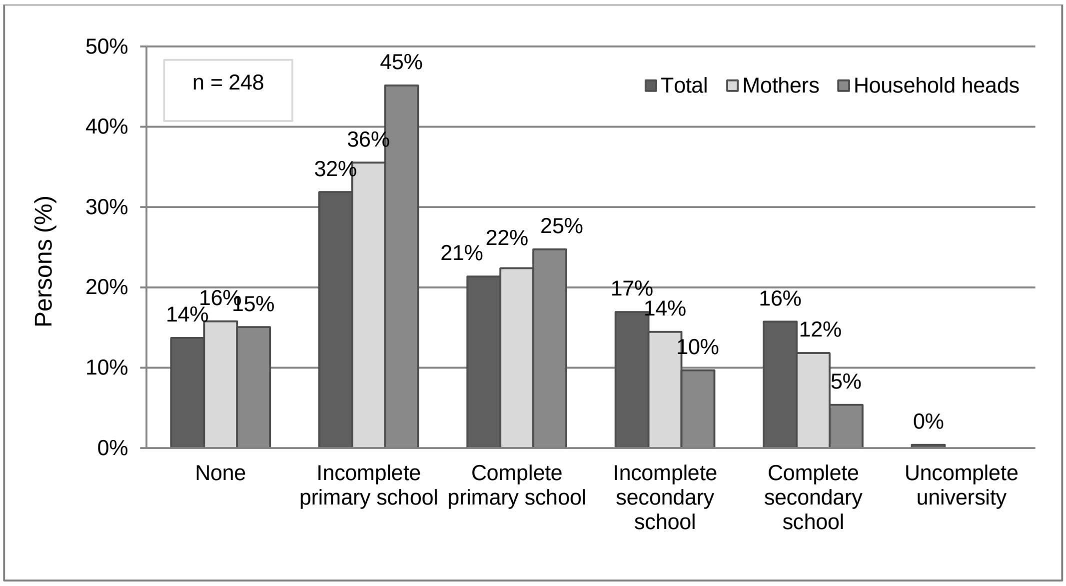


Figure 4-13 Education level of different population groups

Employment

Figure 4-14 summarizes household heads´ employment distribution. Self-employment was the main characteristic. 88% of household heads worked in their own farms, with help from family members. 4% of the household heads were day-labourers, 7% were private employees as farms´ caretakers or maids, and 1% were government employees. Women were generally family workers (82%). A low proportion of self-employees (3%) had small businesses different to agriculture. Only 1% was unemployed. 67% of adults older than 70 years still worked in farming. While the majority of children under 17 years helped in household and farm activities, only one case was found that could be catalogued as child labour.

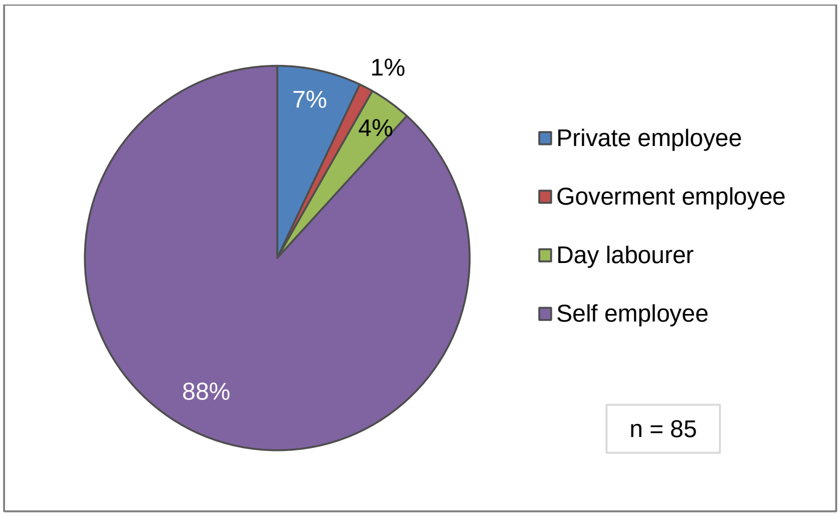


Figure 4-14 Household heads occupation

Livelihoods

Income data were not captured through the household survey, since it was known to be a culturally sensitive issue locally. Furthermore, income data are often inaccurate or not alone represent a household's wealth in places where few people have education, and make their livelihood from a variety of activities (Kanji *et al*., 2012). In these contexts, an approach to livelihoods may be more adequate (Bull, 2009).

84% of farms had coffee growing as their main productive activity, and 12% were involved in livestock farming. 21% of coffee farms also had a few cattle (median 3) and 25% had pigs (median 3). Cattle farming families had less diversified livelihoods. The general average size of homesteads was 6 Ha, with a median value of 3 Ha. However, there were differences between livestock farmers and coffee growers: homesteads from coffee farmers had average areas of 3 Ha, whereas homesteads from livestock farmers had average areas of 19 Ha. Considering relative income factors for the main economic activities and their scale, income level categories were built (Appendix G). Households' distribution according to these categories appears in Figure 4-15. 75% of homesteads were categorized in the first three income levels and only 3% in the highest level.

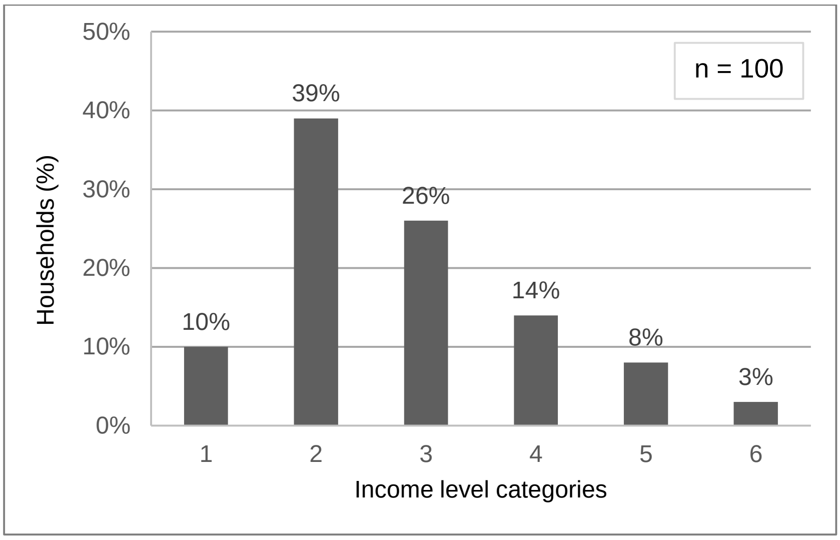


Figure 4-15 Households according to income levels categories

Households in the first category lack of productive assets. Households in categories 2 and 3 had less than 3 Ha of coffee, and those in category 3 had some animal husbandry, few units of pigs and poultry. Households in categories 4, 5 and 6 had diversified livelihoods, and the main difference was in the scale of the activities. Appendix G also includes features of the households in each category according to productive assets.

Housing conditions

73% of families owned their homes. The majority of the surveyed houses were one and two bedroom houses, 37% and 39%, respectively. The average household size was 3 people, generally two adults and one son, daughter or grandchild; the minimum was 1 people (average of 59 years); the maximum was 13 people (5 adults and 8 children). On the basis of the housing occupancy standard of a maximum of three persons for each available bedroom, excluding kitchen, toilet and garage (DANE, 2013), a 7% level of crowding was present. Considering a standard of maximum two people in each available room, the level of crowding increased to 23%. Regarding the constructions, 75% of homes had tile or metal sheets without ceilings. The main materials used for walls were mud (52%) and brick (28%). The predominant material for floors was cement or gravel (47%).

Water

60% of households belonged to four communal Water Supply Systems (WSS): Acuacalabazas, Calabazas, Acuamiravalle, and Acuafenicia, while 40% of homes had individual water systems (Figure 4-16).

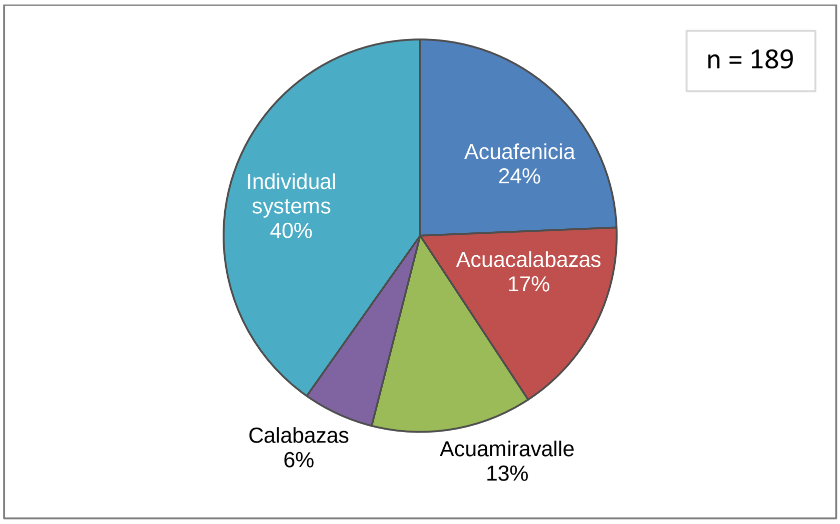


Figure 4-16 Water supply alternatives[8]

Households relied on a single source for all their water needs. Communal systems consisted on piped water into dwellings from protected springs. These systems could be categorized as "improved" (WHO, 2012b; Minsalud, 2013). The infrastructure of communal systems was basic: intake, grit chamber, transmission pipe, storage tank, and distribution network. There was no water treatment, except in Acuafenicia, which had chlorine disinfection. Houses with individual systems took water from unprotected springs, and conducted using hoses. These individual systems could be categorized as "unimproved sources" (WHO, 2012b; Minsalud, 2013). People relying on individual systems tried to keep surrounding native forest and locate their hoses before wastewater discharges or other pollution sources occurred. Detailed results of water quality for the WSS are presented in 4.3.3.

The number of customers in each system is shown in Table 4-3, and Figure 4-17shows the distribution of the systems in the microcatchment.

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[8] This figure was prepared using the list of coffee farms supplemented with information on other households and water supply systems prepared with help from community leaders, as explained in Section 4.2.1. Thus n in this case is greater than the n of the household survey, where 100 surveys were conducted.

Table 4-3 Size of communal WSS

	Calabazas	Acuamiravalle	Acuacalabazas	Acuafenicia
Homesteads served (number)	16	27	83	560
Homesteads served within the microcatchment (number)	11	25	31	46

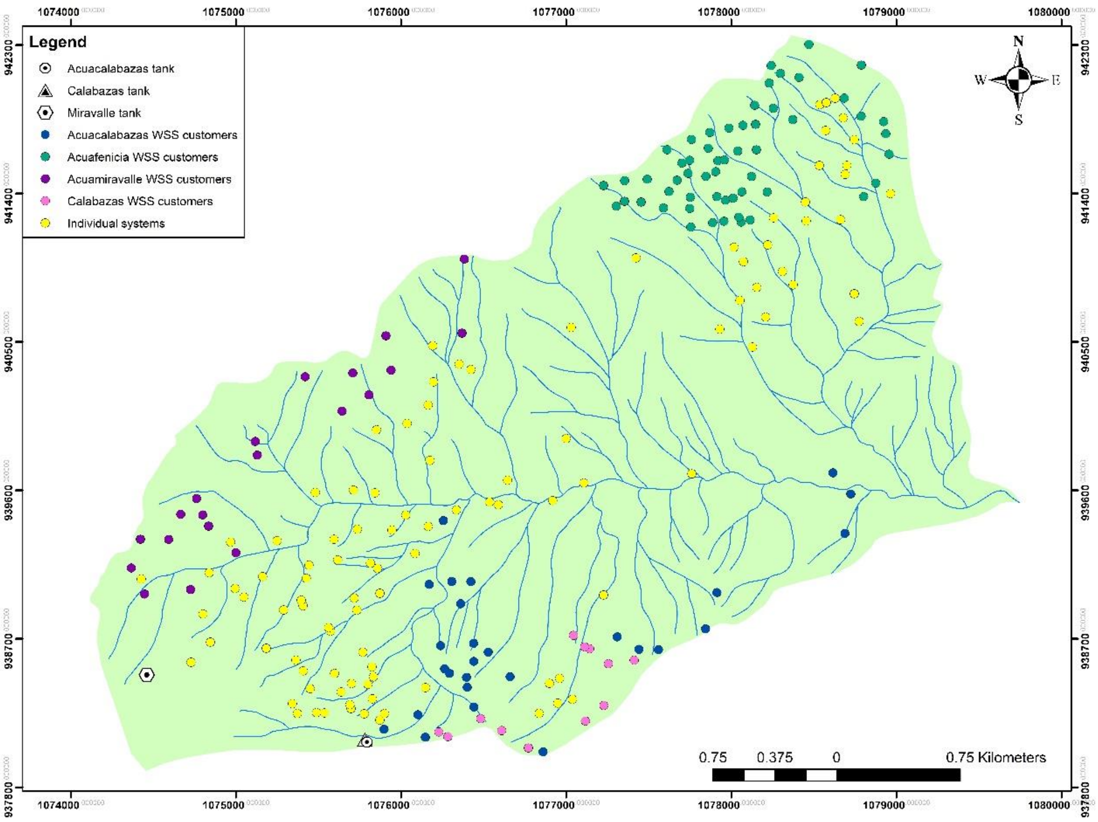


Figure 4-17 Distribution of water supply alternatives

Sanitation

95% of the population had access to improved sanitation, understood as having a toilet in the premises that safely manage excreta (WHO/UNICEF, 2013a). 93% of the households had individual toilets with flush water and 2% had latrines. Toilets were connected to: septic tanks (9%), secondary treatment systems (45%), and soak pits (19%). Some toilets had direct discharges to drainage areas (15%) or to streams (5%). Only 5% of people lack any sanitation solution (Figure 4-18).

The secondary treatment systems were from two types. The first type were prefabricated plastic units, including: grease trap, septic tank and up-flow anaerobic filter. The departmental Sanitation Unit (SU) implemented these systems. The second type were installed by DCC in some coffee farms and comprised the same units as those from SU, but made in concrete. During 2012 and 2013, DCC built 58 individual treatment systems in the area.

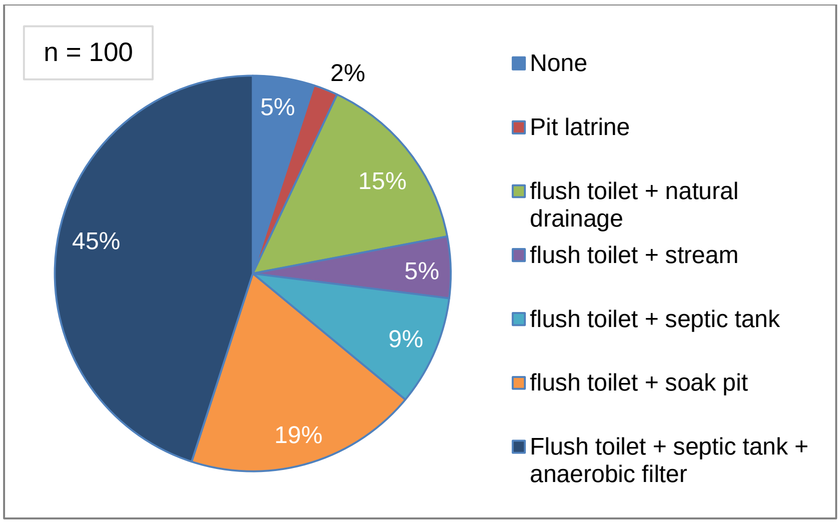


Figure 4-18 Management of domestic wastewater

Other pollution sources were coffee processing and small-scale animal husbandry. Homesteads with pigs disposed their effluents through three alternatives: natural drainage or stream (46%), compost (42%), and soak pits (12%) (Figure 4-19 – a). Coffee processing effluents were disposed mainly through: soil application (64%), natural drainage (20%), and directly to streams (8%). A small proportion used artisanal treatment systems, involving the storage of these effluents to prepare of organic fertilizers (8%) (Figure 4-19 – b).

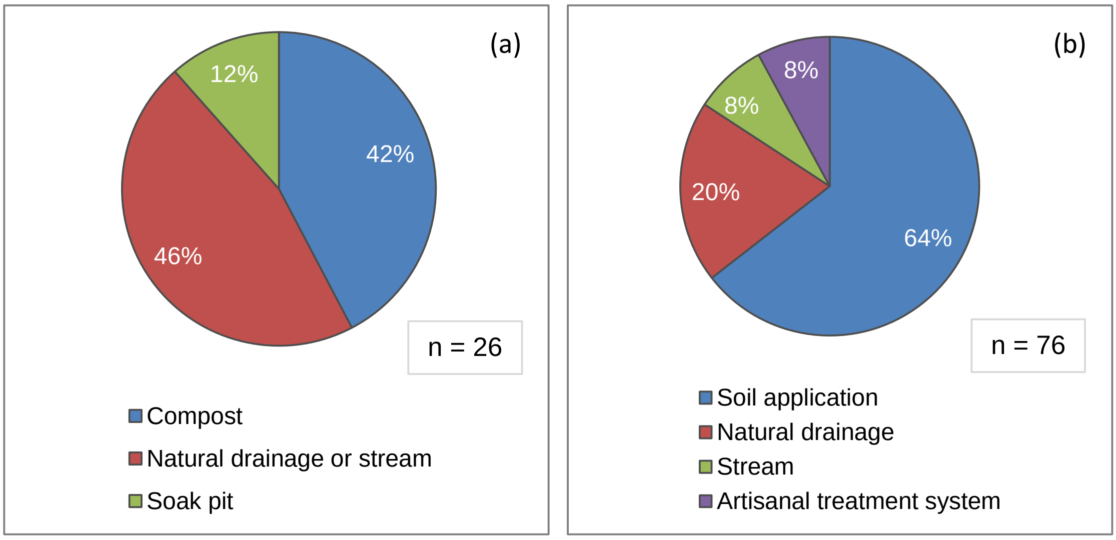


Figure 4-19 Management of wastewater from productive activities

(a) livestock waste; (b) coffee processing waste

Solid waste management

Municipal collection services did not cover the microcatchment. Thus, people used different alternatives to solid waste management. Regarding solid waste from food preparation, 57% of people reused them, either as food for animals (27%) or to produce compost or vermicompost (30%). Some people (40%) disposed this waste in small plots near the houses, close to the crops.

72% of people indicated the use of coffee processing solid waste to produce fertilizers, 61% of which reported having the pits recommended by DCC´s extension staff, as part of the Best Management Practices (BMPs) they promoted. 28% informed disposal of this by-product directly on the soil. Table 4-4 summarizes the alternatives for managing organic solid wastes.

Table 4-4 Alternatives for managing solid waste

Alternatives	Percentage
Food solid waste	
Food for animals	27%
Compost / vermicompost	30%
Burnt	1%
Soil disposal	40%
Buried	1%
	n = 99
Coffee processing solid wastes	
Organic fertilizer	72%
Disposal on soil	28%
	n = 75

Inorganic waste, including packaging of agricultural inputs, were burned, buried or stored, since appropriate management alternatives were not in place.

Infrastructure and transport

The microcatchment was poorly connected to the main urban centres, *Riofrío* and *Tuluá*. With the state of the roads, the distance of about 40 Km from the village located in the west end of the microcatchment to *Tuluá*, *Miravalle*, was approximately 2.5 hours. The distance of this village to *Riofrío* (about 26 Km), was about 1.0 hour. Within the microcatchment, an unpaved 9.7 km road connected the villages to the south of the microcatchment, *San Jose de la Selva*, *Calabazas*, and *Miravalle*. This road was built over an unstable geological terrain (CVC, 1977), and was in a serious state of disrepair. The means of transportation available was a *chiva* (ladder bus), which departures from *Tuluá*, passed by *Riofrío* and reached *Calabazas* village, with service at 6:00 and 16:00.

The second road connected the villages to the north of the microcatchment: *Santa Rita*, *Puerto Fenicia*, *Puerto Arturo* and *Miravalle*. The road was paved up to *Puerto Arturo*, and unpaved but in appropriate state up to *Miravalle*, since it was the access to commercial forest plantations. There was a service with *chiva* and minivan for the route *Tuluá – Riofrío – Fenicia*, at 7:00, 12:00 and 16:00.

The road towards the north of the microcatchment laid by the contour 1800 m. Therefore, the farms located at the foothills of the mountains had great mobility problems to enter and leave of their farms. Walking over long distances was routine for any issue and getting the products out from the farms to the main road demanded significant effort. None of the existing public transport passed by *Miravalle*, as this area was subject to frequent landslides. A document from 1977 reported on the proliferation of tertiary roads in the area, built ignoring minimal technical requirements and the region geology, leading to serious erosion problems (CVC, 1977). All these situations became even more difficult in rainy season when the bad roads were practically inoperative.

Maintenance of the roads was local government's responsibility, but lack of resources interfered with this task (Riofrio, 2012). There was awareness on the fact that the poor state of the roads, limited trade and access public services available in *Riofrío* (Riofrío, 2001). During 2013, DCC ran the *Camineros* program to improve access in the area. *Camineros* hired local people to perform routine and preventive maintenance of roads to avoid further deterioration. However, this program was subject to the availability of funds managed by the NFC through agreements with the State, or otherwise through the National Coffee Fund (FoNC).

Health care

Since 1993, the Colombian government enacted a law aimed at ensuring universal coverage (Ruiz *et al*., 2007), through a nationwide social health insurance program targeting the poor (Arajo *et al.*, 2011). The system in place had three regimes (Ruiz *et* *al.*, 2007; Arajo *et al.*, 2011; Carabalí and Hendrickx, 2012): i) contributive, which cared for those formally employed, and included their families; ii) subsidized, which covered the population unable to pay; and iii) private, available for those who wanted improved secondary and tertiary level services. Those in the contributive and private schemes paid for their own services, and provided to the subsidized population. Since most of the microcatchment population were self-employed or under poor employment conditions, most of the inhabitants (85%) were insured through the subsidized regime, and 8% were not insured (Figure 4-20).

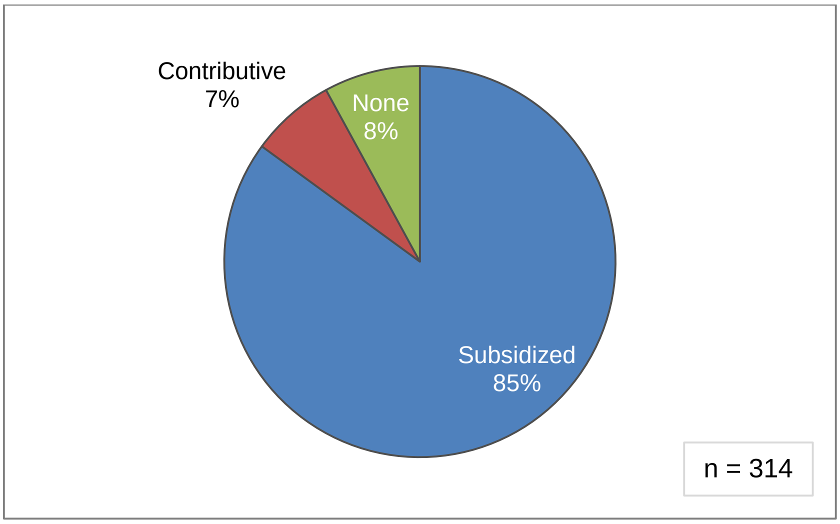


Figure 4-20 Distribution of healthcare regime

The existing health care sites in the microcatchment did not have permanent medical staff, frequency of attention was once a week, the infrastructure was inadequate and improvised; there were no medicines or basic equipment, or mechanisms for emergency care. Most of the medical services were provided in the Kennedy hospital in *Riofrío*, which offered first level of complexity services, promotion and prevention. Although, as with schools, lack of roads in good condition, transport means, and steep topography made difficult access to the limited available services.

Table 4-5 shows cases of common diseases for which the sample population answered positive to the question: last year any of the family members had the disease X? In addition, people were asked if the ill person looked for medical attention or otherwise to indicate the reasons why they did not.

Table 4-5 Common diseases and medical healthcare sought

Disease	Cases (number)	Medical healthcare sought		
		Subsidized (n = 79)	Contributive (n = 10)	None (n = 8)
Diarrhoea (n = 100)	5	1	0	0
Fever (n = 100)	16	4	1	0
Vomiting (n = 99)	7	1	0	0
Acute respiratory infection (n = 100)	5	1	2	0
Total	33	7	3	0

In 33% of households, someone experienced one of the diseases asked, fever having the highest frequency. From the people who became ill, only 30% sought medical attention. Even though, it is noted that most of those who sought care belonged to the subsidized regime, taking into account the proportion of households in each regime, those in the contributive regime were more likely to attend the doctor when they were ill, compare to those in the subsidized regime (30% and 9%, respectively). Uninsured people did not visit the doctor. Among the people who got sick and did not visit the doctor, 24% said it was due to lack of money and 18% due to the lack of a nearby healthcare centre.

Table 4-6 summarizes data about determinants of health for the microcatchment.

Table 4-6 Summary of relevant social determinants of health

Determinant	**Description**	***Calabazas***
Median household size	Number of people per household	3 persons/households
Overcrowding	Proportion of households with more than three persons for each available bedroom, excluding kitchen, toilet and garage	7 %
Illiteracy rate	Proportion of people above 10 years without any education in relation to the total population above 10 years	10 %
Household heads education	Proportion of household heads who studied at least one year of secondary basic education	5 %
Wives education	Proportion of wives who studied at least one year of secondary basic education	12 %
Median size of the homestead	Size of the 50% of the homesteads	3 Ha
Proportion of population using an improved drinking-water source[1]	Proportion of population using a drinking-water source which by nature, construction or active intervention, is protected from outside contamination, in particular from contamination with faecal matter	60%
Proportion of population using an improved sanitation facility[1]	Proportion of population with a facility that hygienically separates human excreta from human contact	95%
Proportion of medical insurance coverage	People ensured to health care under the national system, either as contributive or subsidized	92%

[1] Definitions by WHO/UNICEF (2013a)

4.3.2 Stream water quality

This section presents results of the stream water survey carried out to understand the behaviour of stream water quality as an environmental factor over catchment health and human health and wellbeing. An overview of relevant land use characteristics, followed by results from the assessment to eight water quality parameters are discussed below.

Land uses

According to its biophysical characteristics, CVC (2012) has established land in the microcatchment should be used mainly for: protective – productive forest (21%), productive forest (10%), protective forest (2%), multilayer crops (52%) and dense crops (10%) (Table 4-7). However, as Loaiza (1995) describes, the region experienced substantial land use transformations. From 1910 to 1932, a colonization process took place, keeping natural forests but introducing roads, and grazing lands. From the 1950s to 1970s, the green revolution displaced grazing lands from the valley of Cauca river to the hillside and expanded to coffee growing, increasing crop densities, and adopting agrochemicals. In the 1980s, annual crops collapsed due to economic opening, and sugar cane monoculture occupied the flat lands in the valley, which were monopolized by the big industrial capital and small peasants started colonization of mountain forests lands. In 1982, a transnational forestry company bought livestock ranches and planted Eucalyptus trees. From 1988, few owners accumulated important land extensions to establish livestock ranches. In the microcatchment, for 2008, 63% of the land was under coffee crops; 32% was under livestock, and productive forest was estimated at 2% (Table 4-7). There were some relicts of protective forest, especially on the stream canyons and headwaters.

Table 4-7 Suitable[1] and transformed land use

Land use type	Suitable land use (%)[2]	Land use in 2008 (%)[2]
Land for recovery	1	0
Land for clean crops	1	0
Land for semi-clean crops	3	0
Land for dense crops	10	0
Land for multilayer crops	52	63
Land for productive forest	10	2
Land for productive – protective forest	21	0
Land for protective forest	2	3
Grazing land	0	32

[1] The suitable land or potential land use is defined by CVC (2013) as the natural capacity hold by land to produce or maintain vegetative cover. This natural ability may be limited by erosion, effective depth, slope, chemical and physical characteristics, groundwater levels, and rainfall patterns, among others

[2] Percentages estimated based on information from CVC (2012)

People in the microcatchment were scattered, the density was 0.7 inhabitants/Ha. However, three “nucleated” populations were identified. These three nuclei comprised mainly coffee farms. The denser place was *Calabazas* village (1.2 inhabitants/ha), followed by *Puerto Fenicia* (0.9 inhabitants/ha), and *Miravalle* (0.6 inhabitants/ha). Coffee farms were typically less than 3 Ha, and located in an altitudinal corridor from 1300 to 1800 m. Between 1300 m and 1000 m (the microcatchment outlet), the population was scattered, only 10% of farms existed, most of them dedicated exclusively to livestock, with extensions between 10 and 70 Ha.

General water quality

Table 4-8 summarizes descriptive statistics for the parameters at the four sampling sites (S1 to S4) without considering seasonal influences. Results of the behaviour of each parameter are presented below.

Table 4-8 Geographical distribution of flow and water quality[1]

		Flow (l/s)	pH (Units)	Temperature (°C)	Conductivity (µS/cm)	DO (mg/l)	TSS (mg/l)
S1	Min	2.8	6.7	17.2	90	4.8	0.9
	Max	5.2	8.4	18.3	151	7.6	6.3
	Median	4.3	7.6	18.0	117	6.5	2.5
	Mean	4.3	7.6	17.9	116	6.5	2.5
	Sd	0.7	0.5	0.4	22	0.8	1.5
S2	Min	40.5	7.5	19.6	110	5.0	2.0
	Max	84.1	8.0	21.4	187	8.2	14.0
	Median	62.0	7.6	20.4	149	7.3	4.0
	Mean	62.9	7.7	20.5	143	7.1	5.8
	Sd	16.2	0.2	0.6	24	0.9	4.1
S3	Min	137.7	7.5	19.5	90	4.4	2.5
	Max	416.6	8.1	21.6	150	8.6	8.0
	Median	197.3	7.7	20.6	123	7.7	5.3
	Mean	233.4	7.7	20.7	117	7.3	5.0
	Sd	94.7	0.2	0.7	20	1.2	1.9
S4	Min	202.6	7.6	21.1	110	4.4	1.8
	Max	608.2	8.3	24.5	193	7.9	3.2
	Median	295.8	8.0	22.2	165	7.3	2.5
	Mean	330.9	8.0	22.6	152	7.0	2.4
	Sd	128.7	0.2	1.3	29	1.0	0.4

[1] n = 8 for all parameters at each sampling station S.

Flow

Flow rates measured at S1 averaged 4 l/s. Flow recorded at S4 was higher approximately 50% times of the flow recorded at S3. Maximum flow rates observed at S4 were approximately 600 l/s and minimum flows 200 l/s (Table 4-8).

The average flow at S1 in the rainy season was 3.8 l/s and 4.7 l/s in the dry season (Figure 4-21). Between S2 and S3, *Calabazas* received a substantial contribution from

Miravalle stream, which increased the flow over 200% in dry season and 300% in rainy season. At the outlet, average flow rates were 429.2 l/s for rainy season and 232.5 l/s for dry season. Flow at S1 in the rainy season was lower than for the dry season (23%). However, this behaviour changed for other sites, higher flows occurred in rainy season compared to dry season at S2, S3, S4, with growth of around 34%, 49% and 46%, respectively. At S4, the standard deviation was the highest, 129.6 l/s for the rainy season, and only 39.7 l/s for dry season.

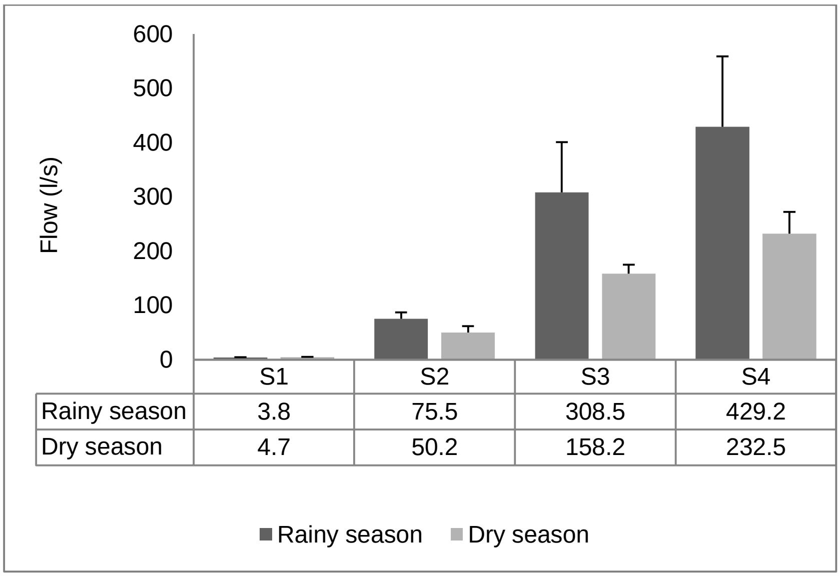


Figure 4-21 Stream flow according to stations and season

n = 4 at each sampling station S in rainy season; n = 4 at each sampling station S in dry season

The four sampling points were statistically different regarding stream flow for rainy (Kruskal-Wallis, $p = 0.0041$) and dry season (Kruskal-Wallis, $p = 0.0027$). Thus, the Mann-Whitney test was used to compare differences between pairs of sampling points. In the rainy season, the flow rate was different between all stations, except between S3 - S4. For dry season, flow was statistically different between all stations (Table 4-9).

Table 4-9 Comparison of stream flow between pairs of sampling points according to season

Season	p values (Mann-Whitney test)		
	S1 - S2	S2 - S3	S3 - S4
Rainy season	0.0286*	0.0286*	0.2000
Dry season	0.0286*	0.0286*	0.0286*

* Statistical significance level $p < 0.05$

Comparing each sampling station, it was found that flow was statistically different between seasons at S3 (Mann-Whitney, $p = 0.0286$) and S4 (Mann-Whitney, $p = 0.0286$).

Temperature

Temperature increased with the length of the stream starting at 17.9°C in S1 and finishing at 22.6°C at S4 (Table 4-8). The same behaviour occurred in both dry and rainy season (Figure 4-22). From S1 to S4, mean temperatures increased in 5.4˚C in dry season and about 3.9˚C in rainy season. S4 had the highest standard deviations of 1.1˚C, during dry season.

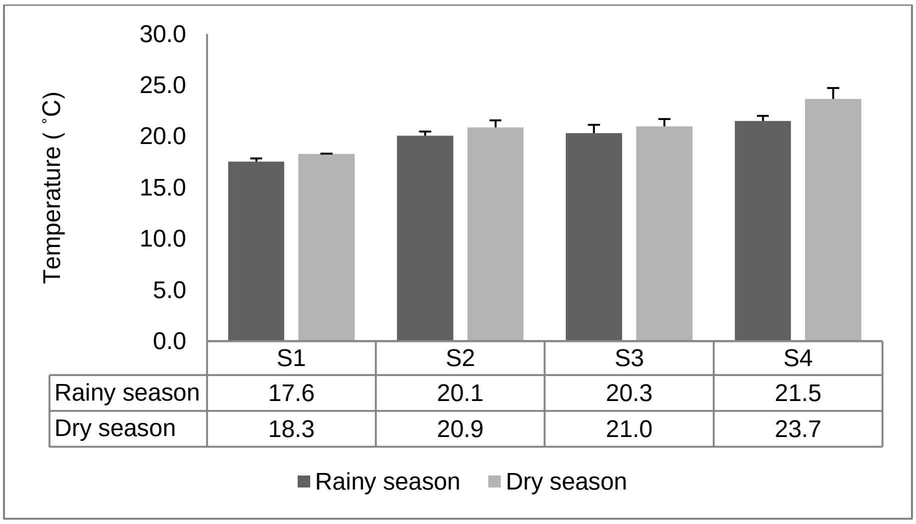


Figure 4-22 Temperature according to stations and season

n = 4 at each sampling station S in rainy season; n = 4 at each sampling station S in dry season

The sampling points were statistically different regarding temperature for rainy season (ANOVA, $p = 1.81E-06$) and dry season (ANOVA, $p = 2.98E-06$). Thus, the Tukey test was used to compare differences between pairs of sampling points, for each season. In rainy and dry season, the temperatures were different except for S2-S3 (Table 4-10).

Table 4-10 Comparison of temperature between pairs of sampling points according to season

Season	p values (Tukey test)		
	S1 - S2	S2 - S3	S3 - S4
Rainy season	0.0001*	0.9082	0.0386*
Dry season	0.0015*	0.9973	0.0012*

* Statistical significance level $p < 0.05$

Regarding differences in temperature at each sampling point between seasons, there were statistically significant differences only at S1 (Mann-Whitney, $p = 0.0256$).

pH

pH was 7.6 at S1, and slightly increased to S3 (7.7). It raised to 8.0 at S4 (Table 4-8). In rainy season, mean pH along the stream ranged from 7.7 to 8.0 and from 7.3 to 7.9 during the dry season. The biggest difference between seasons was at S1, 0.6 units, while the differences in the other sites were between 0.1 and 0.2 units. The highest mean pH was at S4 in rainy season, 8.0 units. Likewise, the standard deviations were lower in rainy season, compared to dry season, at all sampling stations, except for S1 (Figure 4-23).

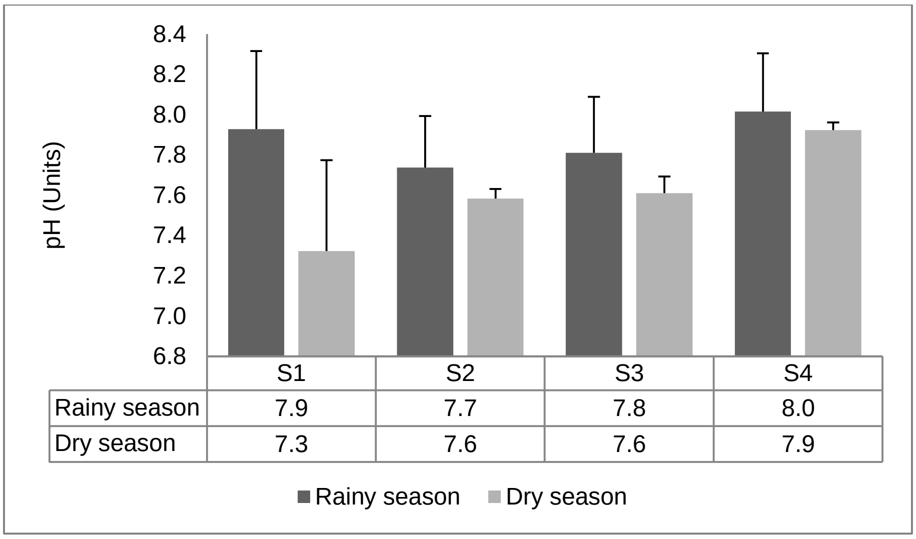


Figure 4-23 pH according to stations and season

n = 4 at each sampling station S in rainy season; n = 4 at each sampling station S in dry season

pH was statistically different at the four sampling points only for dry season (Kruskal-Wallis – dry season, $p = 0.0222$; ANOVA – rainy season, $p = 0.6014$). Thus, statistical tests were carried out to compare differences between pairs of sampling points only for dry season. In this comparison, pH was different only between S3 and S4 (Table 4-11).

Table 4-11 Comparison of pH between pairs of sampling points according to season

Season	p-values (Mann-Whitney test)		
	S1 - S2	S2 - S3	S3 - S4
Dry season	0.6857	0.6631	0.0294*

* Statistical significance level $p < 0.05$

Results from the Mann-Whitney test indicated pH in rainy season was not statistically different from pH in dry season, at any of the sampling stations.

Conductivity

Conductivity increased consistently from 116 µS/cm at S1 to 152 µS/cm at S4 (Table 4-8). The four sampling points were statistically different regarding conductivity only for dry season (Kruskal-Wallis: p dry season = 0.0045; p rainy season = 0.2061). Thus, statistical tests were carried out to compare differences between pairs of sampling points only for dry season. Results from this comparison indicated that conductivity was different between all stations (Table 4-12).

Table 4-12 Comparison of conductivity between pairs of sampling points according to season

Season	p-values (Mann-Whitney)		
	S1 - S2	S2 - S3	S3 - S4
Dry season	0.0286*	0.0286*	0.0286*

* Statistical significance level $p < 0.05$

Concerning differences at each sampling point between dry and rainy season, there were no seasonal statistical significant differences. Thus, it was possible to prepare the box and whisker plot in Figure 4-24. This figure shows conductivity at S2 and S4 was higher compared to S1 and S3, and the variability of measurements at different seasons was similar.

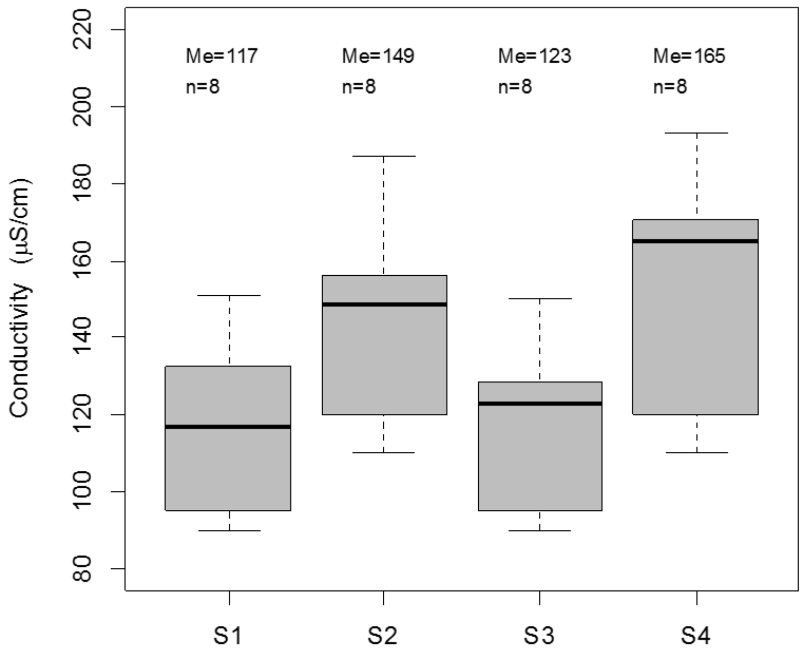


Figure 4-24 Box and whisker plot of spatial behaviour of Conductivity during rainy and dry seasons combined

Dissolved Oxygen (DO)

DO increased from S1 (6.5 mg/l) to S3 (7.3 mg/l) and then reduced at S4 (7.0 mg/l). (Table 4-8). Kruskal-Wallis tests was used to compare medians between the four sampling points in rainy and dry season. The four sampling points did not have statistical differences for any of the seasons. Therefore, it was not necessary to carry out further statistical tests to compare pairs of sampling points. The Mann-Whitney test was performed and no statistical differences in DO at each sampling point between dry and rainy season were found. Figure 4-25 shows DO increased from monitoring S1-S3 and decreased from S3 to S4. Outliers[9] were observed from samples taken during the dry season, with values less than 5.0 mg/l for all sampling stations including the headwaters.

9 Outliers are represented on the box and whisker plots as dots.

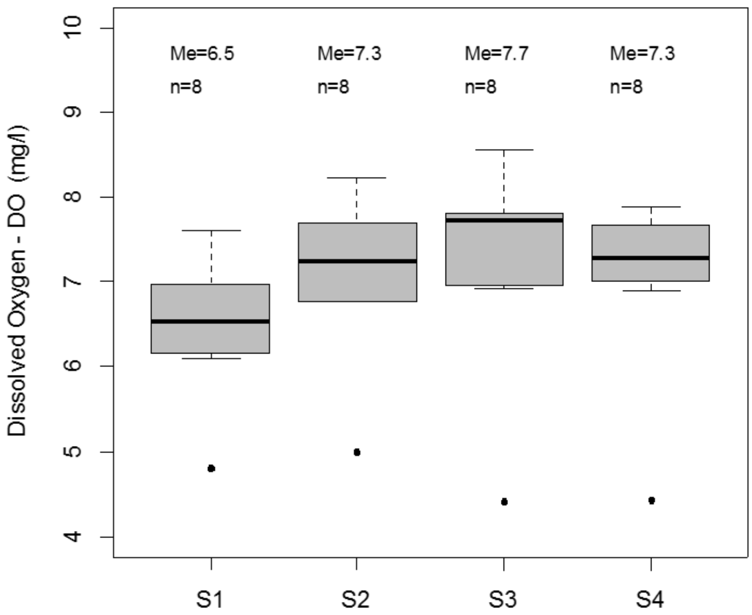


Figure 4-25 Box and whisker plot of spatial behaviour of DO during rainy and dry seasons combined

Biochemical Oxygen Demand (BOD)

All data for BOD collected at all monitoring stations in the rainy and dry season campaigns were below the detection limits of the method (< 3 mg/l). Therefore, it was not possible to show descriptive statistics or perform statistical tests for this parameter. It can be said that there were no spatial or temporal variability for BOD in the microcatchment.

Total Suspended Solids (TSS)

Median TSS increased from S1 (2.5 mg/l) to S3 (5.3 mg/l), and decreased at the outlet up to the initial level (2.5 mg/l). The magnitude of the standard deviations was the highest at S2 (4.1 mg/l), and the biggest outlier occurred at S1 (Figure 4-26). Maximum values of 14.0 mg/l, occurred at S2 (Table 4-8). A high proportion of the TSS data for rainy season were reported below the detection limits of the method (< 5.0 mg/l). Therefore, it was not possible to perform statistical tests to this data set.

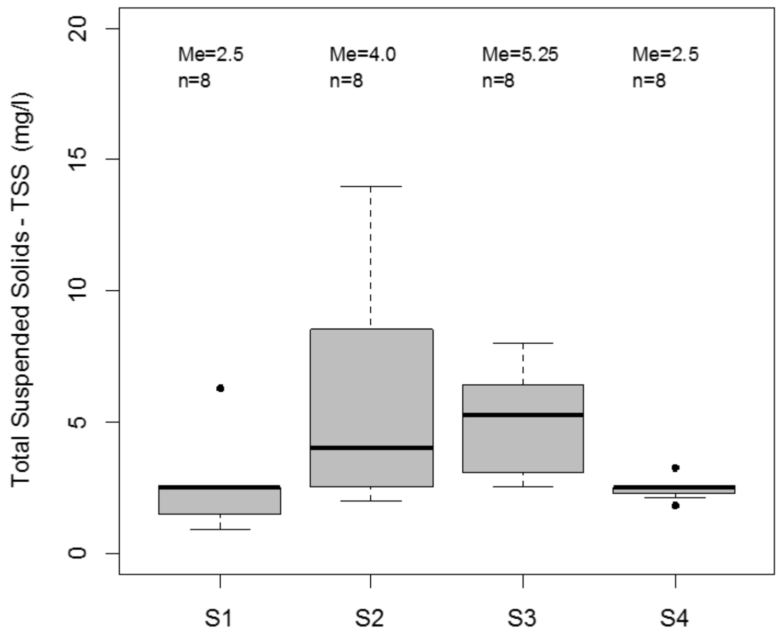
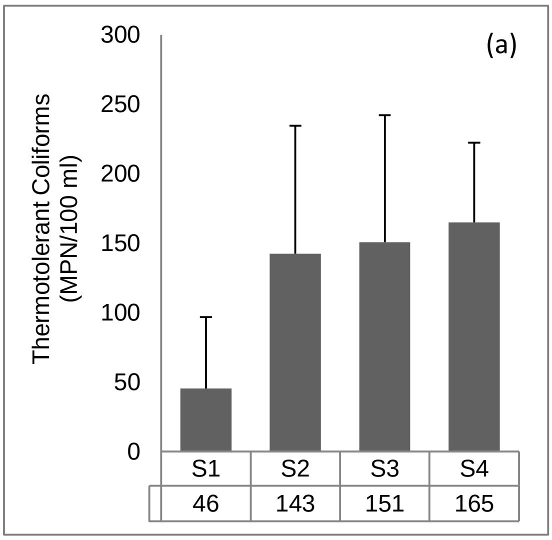


Figure 4-26 Box and whisker plot of spatial behaviour of TSS during rainy and dry seasons combined

Microbial water quality

TTC concentrations observed from S1 to S4 are presented in Figure 4-27. In rainy season, the mean TTC along the stream ranged from 46 to 165 MPN/100 ml. The lowest value was at S1. TTC had a threefold increase from S1 to S2. Then, TTC had a small increase in the course of the stream from S2 (143 MPN/100 ml) to S4 (165 MPN/100 ml). S4, at *Calabazas* outlet, had the highest TTC counts. The highest standard deviations for this season occurred at S2 and S3, with values around 92 MPN/100 ml. In dry season, the trend was slightly different to the rainy season, presenting similar TTC levels between S1 and S3, in the range of 63 to 70 CFU/100 ml, and an increased about 1.6 times between S3 and S4. The standard deviations for this season were more homogeneous, with values at stations between 13 and 18 CFU/100 ml.



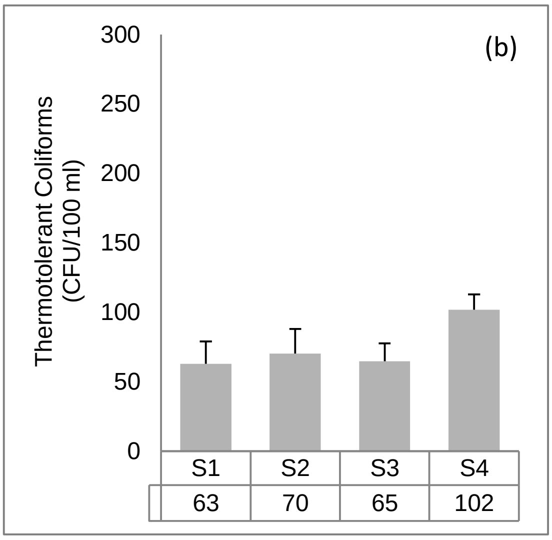


Figure 4-27 TTC according to stations and seasons

(a) rainy season – Most Probable Number; (b) dry season – Membrane Filtration

n = 4 at each sampling station S in rainy season; n = 4 at each sampling station S in dry season

The sampling points were statistically different regarding TTC only for dry season (Kruskal-Wallis, p rainy season = 0.2652; ANOVA, p dry season = 0.0094). Thus, the Tukey test was used to compare differences for TTC between pairs of sampling points only for dry season. In this season, TTC was different between S3 and S4 (Table 4-13).

Table 4-13 Comparison of TTC between pairs of sampling points according to season

Season	Tukey test		
	S1 - S2	S2 - S3	S3 - S4
Dry season	0.8969	0.9507	0.0182*

* Statistical significance level $p < 0.05$

In the case of TTC, it was not possible to determine whether there were seasonal variations at each sampling station, because due to lack of agreement with the Laboratory undertaken water analysis for the stream water survey, the analytical methods used to measure TTC were different between the two seasons. In the rainy season the method of multiple tube fermentation was used, and membrane filtration in dry season. The results of these methods are comparable in terms of trends, but they operate under different principles. Besides, the multiple tube fermentation method generates results of greater magnitudes compared to the membrane filtration method (Cho *et al.*, 2010).

4.3.3 Drinking water quality

Drinking water quality was considered in this research together with stream water quality, environmental factors related to catchment health and human health and wellbeing. This section presents results of the drinking water survey carried out to understand the behaviour of microbial water quality across a variety of water sources used for human consumption. Results from microbial quality on communal systems (improved) and individual systems (unimproved) are presented, followed by comparisons between these two categories (WHO, 2012b). People´s perceptions on drinking water quality are shown with data on household water management practices. Finally, changes in water quality from communal storage tanks to the households taps provided by them are presented.

Water quality in communal systems

Figure 4-28 shows TTC levels in communal systems for rainy season. According to the median values (Me), systems with better drinking water quality were in order: Acuafenicia (0 CFU/100 ml), Calabazas (16 CFU/100 ml), Acuamiravalle (26 CFU/100 ml), and Acuacalabazas (32 CFU/100 ml).

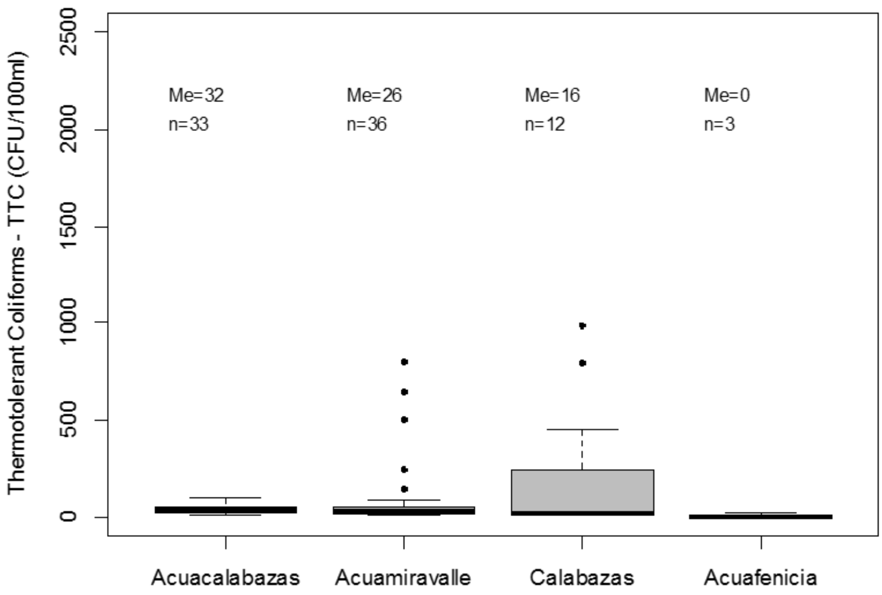


Figure 4-28 Box and whisker plot of TTC levels in communal systems for rainy season

The standard deviations suggest the systems delivering drinking water quality with more consistent TTC levels were in order: Acuafenica (Sd = 9 CFU/100 ml), Acuacalabazas (Sd = 27 CFU/100 ml), Acuamiravalle (Sd = 180 CFU/100 ml) and

Calabazas (Sd = 319 CFU/100 ml). The datasets from Acuacalabazas and Acuamiravalle did not have outliers, while Acuamiravalle and Acuacalabazas had outliers estimated of about 800 and 984 CFU/100ml, respectively. Outliers are represented on the box and whisker plots as dots. In all cases, the median values were below 35 CFU/100ml.

Figure 4-29 shows TTC levels in dry season. The order of the systems with respect to the drinking water quality was similar to the rainy season except that Acuamiravalle had slightly better water quality than Calabazas. The order of best water quality was: Acuafenicia (0 CFU/100 ml), Acuamiravalle (22 CFU/100 ml), Calabazas (29 CFU/100 ml), and Acuacalabazas (32 CFU/100 ml). Contrary to the rainy season, Calabazas had no outliers and Acuacalabazas had a high standard deviation (172 CFU/100 ml) and outliers of 800 CFU/100 ml. As in rainy season, Acuamiravalle had outliers (2100 CFU/100 ml), and Acuafenicia had the lowest standard deviation (6 CFU/100 ml) and no outliers. As in rainy season, in all systems, median values were below 35 CFU/100ml.

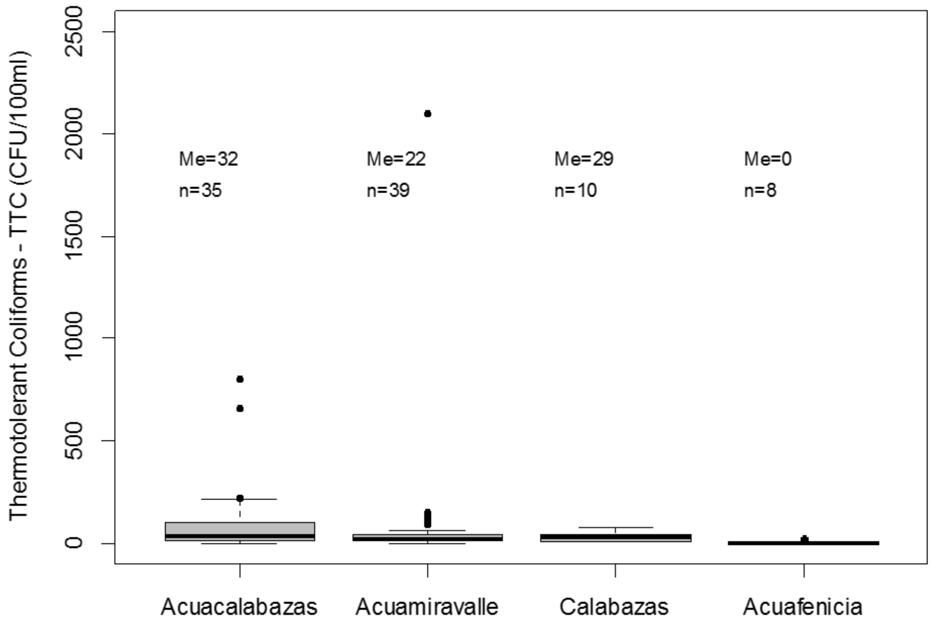


Figure 4-29 Box and whisker plot of TTC levels in communal systems for dry season

In relation to changes in water quality from dry to rainy season: water quality remained the same in Acuafenicia and Acuacalabazas. There was a minor deterioration in Calabazas and a minor improvement in Acuamiravalle. However, these changes were not statistically significant (Mann-Whitney: Acuacalabazas p = 0.5557; Calabazas p =

0.9473; Acuamiravalle p = 0.6067). For Acuafenicia it was not possible to conduct statistical tests for comparisons between seasons due to the low number of users who agreed to participate in the research, which resulted in an insufficient number of data. Figure 4-28 and Figure 4-29 show that with the exception of Acuafenicia, the only WSS with disinfection, the other systems had similar median TTC levels for dry and rainy season. Comparisons were made to determine if there were statistical differences between collective systems without disinfection for each season. The test showed that the three systems (Acuacalabazas, Acuamiravalle and Calabazas) were statistically equal in their TTC median values for rainy season (Kruskal-Wallis test, $p = 0.8351$) and dry season (Kruskal-Wallis test, $p = 0.354$).

Water quality in individual systems

In individual systems, TTC counts in rainy season ranged between 0 and 1800 CFU/100ml. In dry season the range was 0 - 2360 CFU/100ml. Medians were slightly higher for dry season (46 CFU/100ml) compared to rainy season (44 CFU/100ml). Data from rainy season and dry season showed similar variability, 279 CFU/100ml and 271 CFU/100ml, respectively. Greater quantity of atypical data occurred for rainy season, but the magnitude of the atypical data was greater in dry season (Figure 4-30). There were no statistically significant differences in the group of individual systems between rainy season, compared to the dry season (Mann-Whitney, $p = 0.6188$).

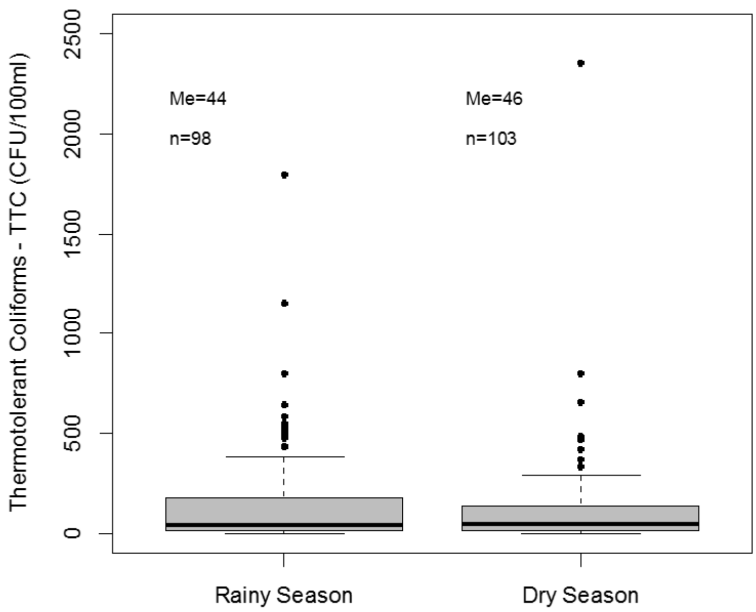


Figure 4-30 Box and whisker plot of TTC levels in individual systems according to season

Differences between individual and communal systems

Since statistical test showed that collective systems were statistically equal for both rainy and dry season, they were grouped into a single category (improved) and compared with individual systems (unimproved). Results showed that improved and unimproved systems were statistically different for dry season (Mann-Whitney, p = 0.03172) and rainy season (Mann-Whitney, p = 0.03685).

Figure 4-31 shows TTC counts comparing the three different water sources categories according to season. Improved and unimproved sources showed median TTC levels were below 50 CFU/100 ml for both seasons. However, improved sources had median lower levels up to 30 CFU/100 ml, while unimproved sources had higher values for both rainy (44 CFU/100 ml) and dry season (46 CFU/100 ml). In rainy season, data dispersion was lower for improved sources (185 CFU/100 ml) compared to unimproved sources (279 CFU/100 ml). In contrast, data dispersion was similar for improved and unimproved sources in dry season, 251 CFU/100 ml and 272 CFU/100 ml, respectively. Improved-D, which was the collective source with disinfection (Acuafenicia) showed the lower values for all the statistical parameters, median 0 CFU/100 ml, and standard deviations of 9 CFU/100 ml (rainy season) and 6 CFU/100 ml (dry season).

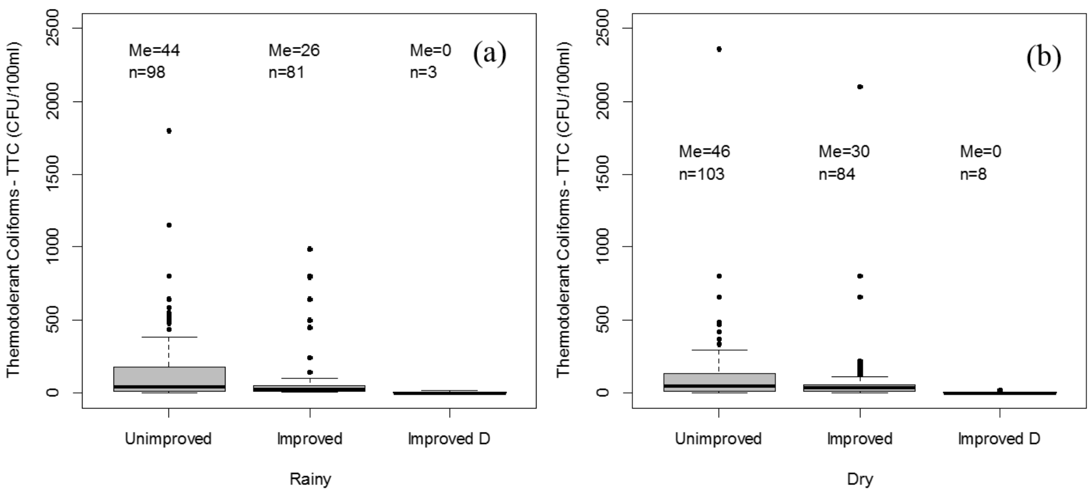


Figure 4-31 Box and whisker plot of TTC levels in improved and unimproved sources according to season[10]

(a) rainy season; (b) dry season

10 Data from improved sources include pooled data from both households and communal tanks, given that there were not statistically significant differences between these two groups (see Appendix H). Data from improved-D only include households since the communal tank of Acuafenicia was not monitored.

Figure 4-32 shows TTC levels according to water source category and season. 5% of samples from improved systems were in the category of < 1 CFU/100 ml for dry season and none for rainy season. Unimproved sources also showed samples in this category for both seasons (5% - rainy season; 7% dry season). In unimproved sources, 34% of the samples for rainy season and 29% for dry season were in the category of higher than 100 CFU/100 ml. In contrast, 10% and 14% of the samples for improved sources had TTC levels above 100 CFU/100 ml. Improved-D had more than 60% of samples below 1 CFU/100 ml for both rainy and dry season.

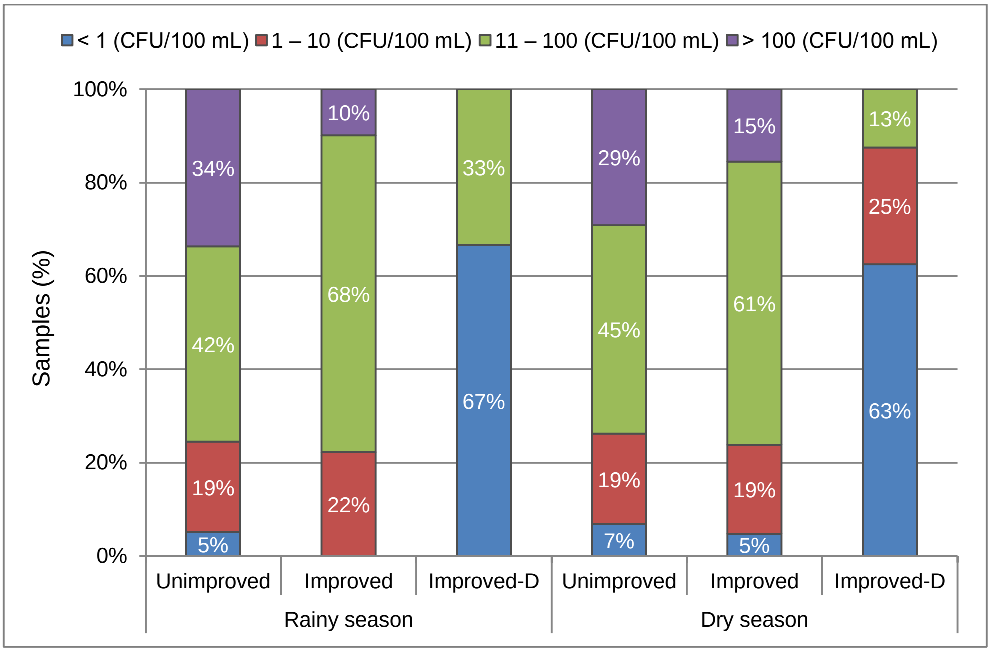


Figure 4-32 Percentage of samples according to TTC level and source category[11]

n unimproved rainy season = 98; n improved rainy season = 81; n improved-D = 3; n unimproved dry season = 103; n improved dry season = 84; n improved-D dry season = 8.

People perceptions on drinking water quality

In most homes people perceived the quality of drinking water as good or very good. In rainy season, 78% of households with access to improved systems and 81% of households with unimproved systems. In dry season, the perception did not vary substantially, 66% of people using improved and 81% of people using unimproved believed water quality was good or very good (Figure 4-33).

[11] Data from improved sources include pooled data from both households and communal tanks, given that there were not statistically significant differences between these two groups (see Appendix H).

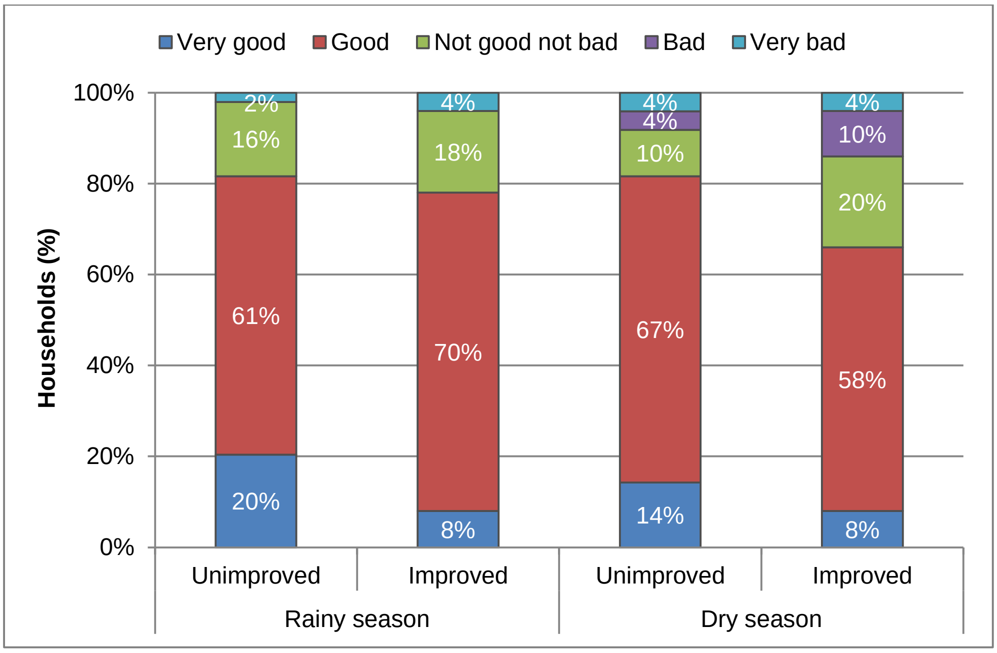


Figure 4-33 People perceptions on drinking water quality[12]

n unimproved rainy season = 49; n improved rainy season = 50; n unimproved dry season = 49; n improved dry season = 50

Changes in water quality from distribution tanks to households in communal systems

Figure 4-34 shows descriptive statistics comparing TTC levels for storage tanks from the communal infrastructure and the households supplied by them for rainy and dry season. Data were aggregated as it was found that there were no statistically significant differences between the communal systems without disinfection. The median TTC decreased from the tanks to the households in rainy season, from 42 CFU/100 ml to 24 CFU/100 ml. The same behaviour occurred in dry season (tank = 40 CFU/100 ml and households = 28 CFU/100 ml). Standard deviations were higher in dry season for tanks (273 CFU/100 ml) compared to households (167 CFU/100 ml). In dry season, standard deviations were substantially higher for the households (269 CFU/100 ml) compared to the tanks (46 CFU/100 ml). There was higher variability for storage tanks in rainy season, whereas households had the opposite behaviour. Despite this decrease in TTC from communal tanks to households, there were no statistical differences between tanks and households in any of the seasons (see Appendix H). Acuafenicia data are not included in Figure 4-34, because its communal tank was not sampled due to the rejection of the managing organization to participate in the research.

[12] This figure was prepared with data from the household survey in which households from Acuafenicia are considered in the category of improved. The category of improved-D was considered only to analyse data from the drinking water quality monitoring.

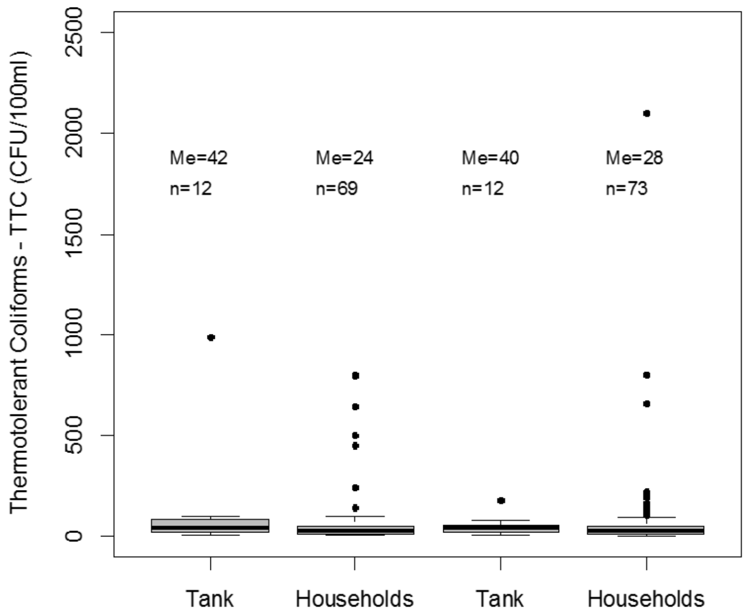


Figure 4-34 Box and whisker plot of TTC levels in communal tanks and households according to season

Community strategies to manage water services

Acuacalabazas and Acuafenicia had community organizations in charge of management, established under the Colombian legislation. These systems had permissions granted by CVC to abstract water, and paid water fees. They fulfilled some legal requirements such as having Statutes and Internal Rules for the Board. None of these organizations, however, had registered with the Superintendence of Public Services, and with the Regulatory Commission of Drinking Water and Sanitation. Managers thought if they registered, they would be in the "radar" of “water privatizers”. Calabazas WSS was the only system where the small number of users (16) and difficulties between them to reach agreements on managerial and particularly tariff issues have prevented them to constitute a formal organization to run the system. This somehow put them at risk, because they lacked the legal right to abstract water.

Table 4-14 shows some financial aspects from the organizations. Tariffs were low and flat except for Acuafenicia, which had differential rates. In this system, when severe damages occurred, resources were obtained from recovery of the default rate. The organization made investments, including replacing pipes, building storage tanks, and improving the office where clients were attended.

Table 4-14 Financial aspects of community organizations

Aspect	Calabazas	Acuamiravalle	Acuacalabazas	Acuafenicia
Accounting books	No	Yes	Yes	Yes
Billing	No	No	No	Yes
Rate (USD$/month) [1]	No	1.6	1.3	2.6 urban and 2.9 rural, 3.7 big users
Default rate (months delay)	N.A.	6	3	3
Service cuts during the last year (number)	None	1	None	23
Subscription fee (USD$/enrolment)	Not known	Not known	26.6	53.1
Expenditures for 2011 (USD$)	No	267	769	14,665
Treatment costs [1] (USD/year)	None	None	None	3,060
Annual balance sheet	No	Yes	Yes	Yes
Budget	No	No	No	Yes

[1] Values for 2012; N.A.: Not Applicable

Acuacalabazas managers believed the resources from tariffs were sufficient for Operation and Maintenance (O&M), but scant if major repairs or expansions were needed. To address the lack of resources, the board carried out O&M activities involving users. For example, gatherings were made to plant trees at the headwaters and people contributed with trees from their farms from local species known to be adequate to preserve water. When damages occurred, additional contributions in money and labour were requested to customers. In Acuamiravalle, managers believed the money raised was enough because no personnel were hired. In this way, resources from tariffs were only for small investments and repairs. Calabazas WSS did not charge tariff. Therefore, when damages occurred, conflicts arose among users because there were no mechanisms or resources to deal with problems.

Table 4-15 presents information related to the availability of staff and their training for the systems. Calabazas WSS did not have a caretaker. The first user, a retired senior of about 70 years, usually performed system labours without support from other users. In Acuacalabazas, a caretaker was hired under a salary that failed to meet legal standards. The organization was interested in providing training to the caretaker to perform his duties, and to be certified by the National Learning Service (SENA). However, this would be difficult since the caretaker was illiterate. In Acuamiravalle, in the absence of caretaker, the General Assembly established three groups of nine users to perform monthly maintenance tasks such as cleaning the intake, washing the grit chamber and storage tank. Occasional and emergency repairs were also made under this modality. In Acuafenicia, the secretary had incomplete university and the caretaker completed high school, but lacked the SENA certificate. Additionally, they were the only workers from the researched systems, who received the current legal minimum wage and benefits. In all the systems, funds were not available to train personnel.

Table 4-15 Personnel and capacities of community organizations

Aspect	Calabazas	Acuamiravalle	Acuacalabazas	Acuafenicia
Employees (number)	0	0	1 (Caretaker)	2 (Caretaker and secretary)
Salary of employees (USD/month)	ad honours	N.A.	37.2	313 Legal monthly minimum wage and benefits
Caretaker educational level	Incomplete primary school	N.A.	Illiterate	Complete secondary school
Caretaker certification	No	N.A.	No	No
Secretary educational level	N.A.	N.A.	N.A.	Incomplete college
Training	No	No	No	Yes, but considered insufficient
Funds for training	No	No	No	No
Project management to look for funding	No	No	No	No
Availability of inputs, tools and spare parts for system´s operation	Non-existent	Provided by the users when needed	Insufficient	Sufficient
Lab equipment and supplies for routine analysis	Inexistent	Inexistent	Inexistent	Inexistent

N.A.: Not Applicable

Challenges for service provision expressed by the managers included in Calabazas WSS: lack of agreement among users to create an organization or join an existent; lack of participation of users in O&M; and lack of all kind of resources to develop the most basic tasks. In Acuamiravalle, leaders identified as main issues the conflicts among users and between users and Board due to insufficient water in dry season that demanded shifts for provision. In Acuacalabazas, problems were related to: valve manipulation by some users leaving others without service during intense dry seasons; crops under agrochemical use upstream from the intake; increase in turbidity in rainy season. In Acuafenicia difficulties identified were: confrontation with the municipal government for the control of system; conflicts with the forestry company, which owns the land in the headwaters; objection of some users to water chlorination and; community complaints for service outages in rainy season due to loss of water quality.

Inspections to the systems identified challenges related to the infrastructure and risks to water quality. Some of these challenges included: i) influence of landslides in intake areas; ii) non-native trees (Eucalyptus) surrounding headwaters; iii) lack of tight lids in grit chambers; iv) inadequate hydraulic performance in grit chambers; v) pipes laid in areas subject to landslides; vi) lack of valves, fittings and repairs in pipes; and vii) lack of tight lids and fences on storage tanks. For most of these challenges, communities were aware and implemented local solutions, in the cases where water associations existed and people was mobilized to address the problems. For instance, local solutions were implemented to deal with the lack of ownership of the lands surrounding headwaters, and the need to protect these areas. To overcome damages on the pipelines due to landslides and to manage hydraulic problems, communities undertook artisanal repairs using locally available materials. These repairs were made using only common sense and despite the fact, they allowed continuous system operation, they were highly vulnerable to new failures.

Other situations were not seen by community organizations as areas for improvement. For example, the need of fittings and valves for optimum hydraulic operation, and the inadequate functioning of grit chambers. All these systems had more than 40 years use, and after they were built, builders left and the communities faced increasing demands for water with the same infrastructure capacity, and deterioration of units and pipes, due to the lack of resources for investment. Thus, communities made empirical repairs, without technical knowledge or external assistance. Additionally, there was awareness on the risks to water quality, caused by external stakeholders such as landowners upstream headwaters. However, there was no awareness of the risks under their governance, as the presence of cattle that were seen in areas where grit chambers or storage tanks were located, and the absence of tight covers, locks and fences. In all these aspects, the lack of external support to assist communities in service provision was evident.

External support

Community organizations faced challenges that sometimes exceeded local capabilities and for which support from external organizations was required. This external support should include the municipal government, which legally must ensure services are provided. Investment of the municipal funds obtained by law from the national government for water and sanitation depended on political will and there were no evidence of such investments conducted by the municipality in the microcatchment. The water systems were built by DCC, and homes that had individual sanitation systems got them by initiatives from the SU or DCC.

Leaders from Acuamiravalle expressed they eventually received support as materials for emergency repairs, as “payment for political favours”. They also requested government support to solve conflicts that arise with users, when adjusting tariffs, or during dry season. Other managers indicated support was not requested because they feared that "*they take the water away from us*". In general, managers expressed they wanted training in O&M, and accounting. However, the local government organized training on job skills for caretakers, but the training was offered to staff from the City Hall with no relation with the rural systems. One of the concerns was the systems´ control was given to a joint public-private entity the municipal government tried to constitute. Three Municipal Agreements were issued to create this entity, but the community stopped these initiatives with mass demonstrations. In spite of this, according to the community, the threat persisted.

Besides implementing individual sanitation systems, the SU had relations with Acuacalabazas and Acuafenicia with two main activities: i) undertaking analysis of water samples twice a year; and ii) running a program to install disinfection units and provide one-year assistance after the systems were in place. However, systems´ managers felt SU made demands that were out of reach of small systems with precarious resources. Concerning the disinfection units, after the year of support, facilities provided to Acuafenicia were in good condition and working. Acuafenicia spent monthly on chlorine around $266 US, accounting for 20% of total system costs. In contrast, the disinfection system installed in Acuacalabazas was abandoned (Figure 4-35). Acuacalabazas´ administrators said they realized they would not be able to bear the costs of chlorine and some users who considered chlorination inadequate for crops and coffee processing rejected the system. Regarding acceptance of chlorination, one person said during a meeting with the leaders (Q42):

Q42: *“I think the treatment plant is very important and hopefully we could get money to build the plant, but I think, you know the government is very smart, and they would say, we give you the plant, but you commit to buy us the chlorine. I disagree on this issue, because here in the countryside if we have a system with chlorine, our agricultural products will disappear. We will no longer have small fish, or productive things, because chlorine will bring problems”.*

Figure 4-35 Acuacalabazas´ chlorination system abandoned

In relation to support from NGOs, the four WSSs in the study area were built by DCC in the 1970s during the coffee boom, when the organization heavily invested on infrastructure in the coffee regions. However, since the coffee crisis, the guild is less able to undertake this type of investments with their own resources, and less often, develops community projects in water supply. However, the National Federation of Coffee Growers (NFC) continued leveraging funds from international cooperation to undertake interventions. In the study area, the NFC through DCC, developed in particular: i) construction of facilities for pollution control, and ii) natural forest preservation through capacity building programs.

The forestry company that owns plantations in the study area had an NGO, which led initiatives on: education, income generation, health improvement, and sustainable use of natural resources. However, there was no evidence on projects from this NGO in the microcatchment. Conversely, people identified this company as an environmental problem (see Section 3.3.3). Furthermore, Acuafenicia had a conflict with this company because the system’s intake was located in lands from this company, under commercial forest in which presumably fumigation, logging and other activities that affect water quality were developed. The community took this conflict to higher stances of arbitration as the Environmental Authority for Valle del Cauca Department (CVC) and the General Comptroller of the Republic. In the end, they desisted for fear of company retaliation. The community was hoping to get resources to relocate the intake.

Household water management

Figure 4-36 shows some water management practices in households´ users of improved and unimproved systems. Overall, there were relatively low levels of water storage and household water treatment. A slightly higher proportion of users of unimproved sources stored water (41%) compared with users from improved sources (35%). Both groups had the same proportion of households developing water treatment (33%), boiling being the alternative in all cases.

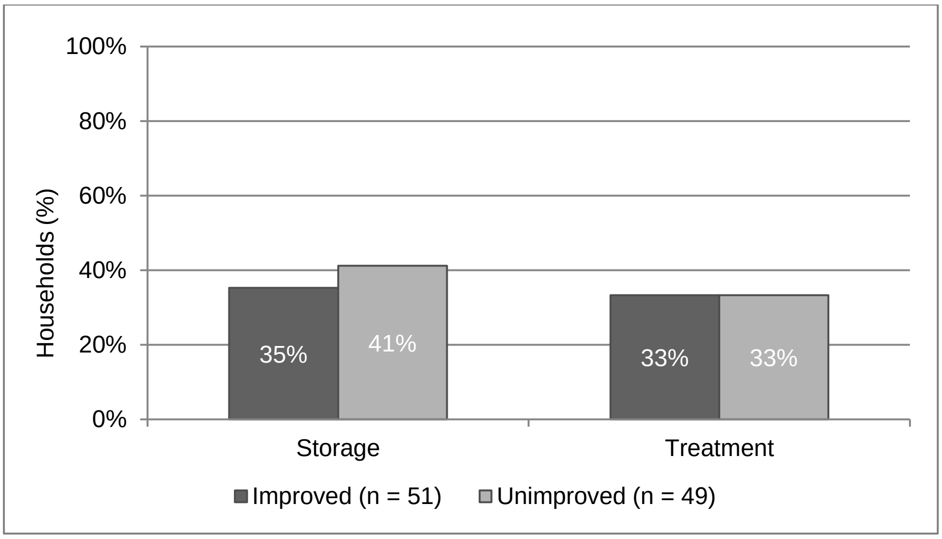


Figure 4-36 Water management practices at the household level

4.3.4 Health outcomes

This section includes information on health outcomes for the population in the microcatchment, using diarrhoea as an indicator. Data on the community perception about the disease and its prevalence during the study period are also presented.

People perceptions on diarrhoeal disease

Over 64% of respondents, using improved sources indicated the risk to acquire diarrhoea was low or very low. A slightly higher proportion of users from unimproved sources perceived the risk in these two categories (67%) (Figure 4-37).

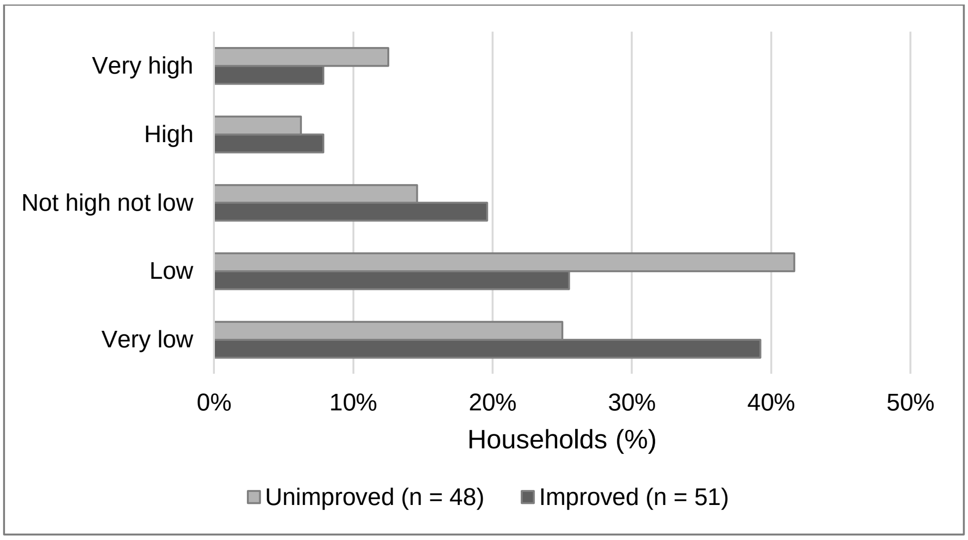


Figure 4-37 Perception of the risk to acquire diarrhoea

People were also asked about the severity of diarrhoea when they suffered an episode. Most people considered the severity being high or very high: 79% of those using an improved source and 83 % using unimproved sources (Figure 4-38).

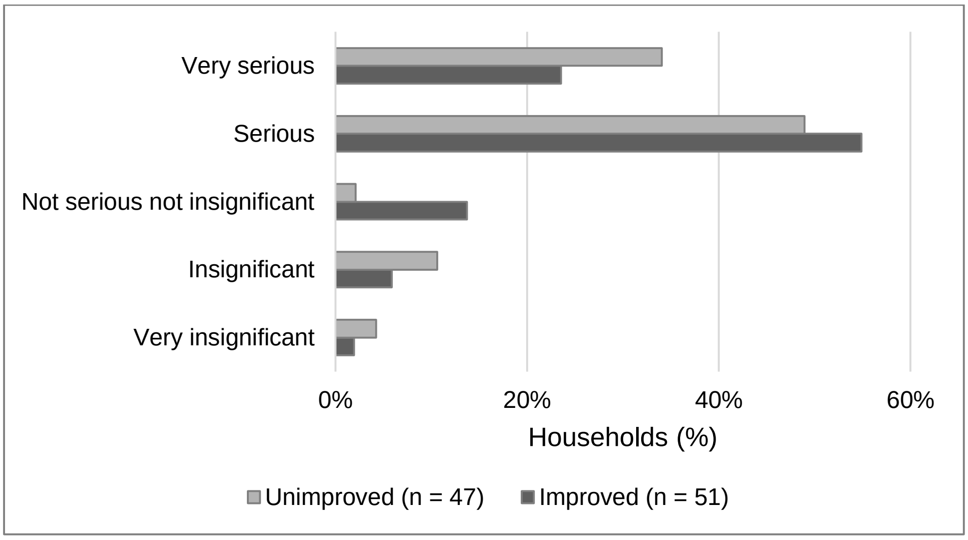


Figure 4-38 Perception of diarrhoea severity

Diarrhoea prevalence

For the 47 households and schools in which drinking water samples were taken fortnightly, four times in rainy season and four times in dry season, people were asked about diarrhoea episodes over the two weeks preceding the survey. People reported diarrhoea in 7% of the households; 16 cases from which three people had two episodes. In five households with cases, more than two family members got sick. Excluding double cases, the rate was 8.2% (N = 159), and all cases were in rainy season, 11 the same week.

People who got sick were women (7) and men (6), in an age range between 7 and 65 years old. Eleven cases occurred in households classified in proxy income levels between 0 and 2, and three cases occurred in overcrowded dwellings. Six cases were in households with access to unimproved water sources and seven on houses without floor. Nine cases were in houses where results from the drinking water monitoring found estimated TTC levels exceeding 600 CFU/100 ml. The remaining cases were in houses with maximum values less than 150 CFU/100 ml. Nine of the cases occurred to people that perceived a low risk of getting diarrhoea. 11 cases reported not treating drinking water (boiling), and seven were in houses where water was stored. All the houses had improved sanitation. The main features of the cases are summarized in Table 4-16. The small number of cases and potential multiple factors involved did not justify conducting statistical analyses to determine causation.

Table 4-16 Summary of diarrhoea cases during the study period

Case	Age (years)	Gender	Proxy of income	Floor material	Crowding	Sanitation system	Water source	HWS[1]	HWT[2]	Max TTC[3] (CFU/100 ml)	Diarrhoea risk perception	Date of illness	Season	Episodes (number)
1	7	F	2	None[4]	No	Improved	Unimproved	No	No	132	Low	Week 3	Rainy	1
2	8	F	2	None	No	Improved	Unimproved	No	No	132	Low	Week 3	Rainy	1
3	12	F	2	None	No	Improved	Improved	No	No	640	Low	Week 3	Rainy	1
4	17	M	2	Cement	Si	Improved	Improved	Yes	No	656	Very low	Week 3	Rainy	1
5	17	M	2	None	No	Improved	Unimproved	Yes	Yes	800	Don´t know	Week 3	Rainy	1
6	20	M	2	None	No	Improved	Unimproved	Yes	Yes	800	Don´t know	Week 1	Rainy	1
7	26	M	2	Cement	Si	Improved	Improved	Yes	No	656	Very low	Week 3	Rainy	1
8	28	F	2	None	No	Improved	Improved	No	No	640	Low	Week 3	Rainy	1
9	29	M	2	Cement	Si	Improved	Improved	Yes	No	656	Very low	Week 3	Rainy	1
10	42	F	3	Cement	No	Improved	Improved	No	No	60	Very low	Week 3 and Week 4	Rainy	2
11	46	F	2	None	No	Improved	Unimproved	No	No	132	Low	Week 3	Rainy	1
12	63	F	1	Cement	No	Improved	Unimproved	Yes	No	800	Not high not low	Week 2	Rainy	2
13	65	M	4	Tile	No	Improved	Improved	Yes	No	796	High	Week 3 and Week 8	Rainy and dry	2

[1] Household water storage; [2] Household water treatment; [3] Maximum level of TTC estimated; [4] Refer to without floor

4.4 Discussion

This section analyses results on the socioeconomic (social determinants) and environmental (drinking and stream water quality) factors related to catchment health and human health and wellbeing in *Calabazas* microcatchment. The discussion is structured in the same way the results were presented: social determinants of health, stream water quality, drinking water quality, and health outcomes.

4.4.1 Social determinants of health

Selected socioeconomic factors or social determinants of health in the microcatchment were elicited from a household survey. The behaviour of aspects such as: demographics, education, employment, livelihoods, housing conditions, water, sanitation, solid waste management, infrastructure, transport and health care were presented.

The main demographic characteristics were low fecundity, a higher male population, and the preponderance of people about 40 years. For each 151 men there were 100 women, while the national ratio was 97:100 (Minsalud, 2013). This pattern was consistent with other rural regions in Colombia, since many women have migrated to cities, due to the relative absence of employment opportunities for them in the rural areas (DNP, 2007). Birth rates were low, about half of national rates. For each 100 fertile women (15 – 49 years old) there were 18 children, whereas for the country this value was 35 (Minsalud, 2013). Only 40% of the inhabitants were under 30 years, and the ratio of infants younger than 5 to elderly over 60 was 1:6, well above the Colombian projection for 2050, which is 1:3 (Gómez *et al.*, 2009). In general, there was a relative ageing in the population, which could be related to migration of the males between 25 and 40 years, and females between 20 and 40 years. The greatest male population was within the fringe 15 – 19 years, and for female between 10 – 14 years, perhaps because in these age groups there were still education alternatives in the territory.

Migration from rural to urban areas is an important global phenomenon (Malik, 2013). Thus, investment in infrastructure and public services in rural areas is seen not only as necessity to redress the widening welfare gap that has arisen between rural and urban settings, largely responsible for migration, but also to tackle pressures at different levels associated to overpopulated cities (CSDH, 2008; Marmot *et al.*, 2008). Urbanization has occurred at large scale in Latin America and the Caribbean (LAC), including Colombia

(Malik, 2013) where up to 1950s urban population was around 40% (Sardi, 2007) and it reached 76% in 2012 (Minsalud, 2013).

Another phenomenon was ageing and the decreasing of the working-age population. With this tendency, a substantial amount of elderly without family support, lack of economic backing and ability to generate income would be expected in a near future, anticipating a social problem. Evidence of this situation was observed during fieldwork, where elderly over 90, were living alone and depending on the neighbours´ charity. The Human Development Report (HDR) 2013 (Malik, 2013) highlights that developing countries experiencing this phenomenon will lose the opportunity for development created by the demographic transition.

Regarding education, in the microcatchment, access for the school-age population declined as youth get older, decreasing from 100% coverage for children enrolled in primary to 22% for the young between 18 to 24 years. While there was universal primary education and reasonable coverage of high school, limitations in access existed including remoteness and transport costs. Furthermore, quality was deficient.

The picture was more daunting for adult education. People older than 15 years without any education were 14%, more than the double compared to the national figure, 6% (Minsalud, 2013). Only 16% of the population completed secondary school, compared to 43% that achieve this level in the country (Minsalud, 2013). Household heads had 4.4 average school years and mothers 5.1 years. The average school years for the population between 15 and 24 years was 8.9, while the National figure being 9.4 (Minsalud, 2013). These figures highlight the urban-rural gap and reveal the inequitable conditions faced by people in rural areas in Colombia. Education is widely recognized as a major determinant of health (Marmot *et al.*, 2008), a path out of poverty for disadvantage groups (Bambra *et al.*, 2010), and a powerful tool to reduce inequity (Malik, 2013). These restrictions on access and quality of education may limited for the people in the microcatchment the possibilities to obtain better jobs, increase income and social participation, and improve the essential conditions for good health such as access to nutrition foods, quality of housing, among others (Bambra *et al.*, 2010; Malik, 2013).

In the microcatchment, 16% of mothers did not have any school education and only 12% completed secondary school. Educated women are likely to have less, healthier and better educated children, and the education level of mothers is more important for child survival than income (Malik, 2013). This indicator has been found a protective factor against diarrhoea (Cáceres *et al.*, 2005), and low school levels from mothers is associated with diarrhoea prevalence in developing countries (Ferrer *et al.*, 2008; Bbaale, 2011). Low education limits the ability for people to access, learn and understand information about disease prevention and management (Carabalí and Hendrickx, 2012), and is a determinant of water management practices at the household level (Nagata *et al.*, 2011). The low educational level of women in the microcatchment could be a limiting factor for achieving improvements in health and wellbeing.

With regards to employment, the situation was poor, characterized by self-employment, employment without remuneration, precarious employment, lack of jobs, and elderly workers. This was perhaps one of the most important problems in the area, since adequate work is an essential social determinant of health, from which other determinants are dependent (CSDH, 2008; Bambra *et al.*, 2010). Except farm managers, about 90% of the population was under precarious work, which failed to ensure a fair income and access social security. Unemployment, informal work and temporary work are associated with poor health status (CSDH, 2008). In rural communities, studies show that poor job conditions are linked to increased morbidity and mortality (Barnidge *et al*., 2011). Furthermore, 67% of adults older than 70 years still worked in farming activities. This pattern is common in Colombia, in which most of rural elderly are involved in agricultural work, while they still have strength, since generally no access to social security is provided. These people often get less income from their work compared to the younger and are at great risk of getting incomes below the poverty level (Gómez *et al.*, 2009).

Even though, from the total population only 1% was unemployed, a figure lower than the national unemployment rate 10.7% (DANE, 2014b), this low unemployment rate could be explained on the demographic distribution, since people who have not found employment could have already migrated. Employment distribution reflected the limited opportunities in the area. Self-employment and migration emerge when other employment opportunities are limited to find ways to make a living (Barnidge *et al*., 2011). In Colombia, migration of young farmers looking for work to urban areas is frequent (Gómez *et al.*, 2009).

The lack of decent working conditions in the microcatchment could lead to migration, perpetuate poverty and social inequities, and prevent the realization of conditions necessary for health and wellbeing. Lack of decent jobs and the increase of educated individuals have led to the proliferation of social unrest around the world (Malik, 2013). In 2013, Colombia experienced this situation, when the largest agrarian demonstrations in the country´s history took place, led by farmers, including coffee farmers, desperate for been dragged into poverty as result of absence or harmful policies (revaluation, free trade agreements, lack of controls to smuggling, prices of inputs). *Calabazas´* farmers participated in these demonstrations that lasted several weeks.

The small size of most plots due to subdivision of land over generations, limited the ability to develop profitable coffee and livestock production in *Calabazas*, restricting the possibility for sustainable livelihoods. One of the most important factors on rural poverty is insufficient access to land (Malik, 2013). The impossibility to earn a reasonable income from agriculture, restrict accessing food, services such as water and sanitation, and health care (Hawkes and Ruel, 2006). In *Calabazas*, some families increased income diversification as a strategy for survival. The low-income levels threaten the possibilities for rural health equity (CSDH, 2008).

A higher proportion of homes (17%) compared to the national figure of 10% (Minsalud, 2013) were built with inadequate materials, mainly lack of floor. These 17% of the population and the 7% living in overcrowding could be at greater risks of experiencing disease, and particularly diarrhoea morbidity, since this has been identified as a significant factor elsewhere (Bbaale, 2011; Khan *et al.*, 2013). In Colombia, studies at the national level have found that as the percentage of people living in inadequate housing increases, so does diarrhoea mortality rate in children under 5 years (Minsalud, 2013). In addition, there was 7% overcrowding (or 23%, depending of the standard considered as discussed in Section 4.3.1), which is also recognized as an important factor on the general functional state of household infrastructure and hygiene conditions (Bailie *et al.*, 2010), and one of the socioeconomic determinants most frequently associated with diarrhoea morbidity (Bates *et al.*, 2007; Ferrer *et al.*, 2008; Bbaale, 2011; Khan *et al.*, 2013)..

Concerning water infrastructure, 60% of households had access to improved water systems. In rural areas in Colombia, the estimated average water supply coverage was

72% in contrast to urban areas, where coverage was 100%. Access to improved water was lower for the rural Colombia (72%) than for LAC (81%) (WHO/UNICEF, 2013a). Coverage of improved water supply in the microcatchment (60%) was lower compared to rural Colombia (72%), rural LAC (81%), and much lower than the urban area of Colombia (100%). In Colombia, this gap has been explained by the focus of public policy on increasing coverage in urban areas to the detriment of rural areas, and the lack of programs that provide technical and managerial support to community organizations running rural services (Ramírez *et al.*, 2012).

In the microcatchment, people with access to both improved (communal) and unimproved (individual) systems generally enjoyed access to water in sufficient quantity and continuously, normally piped to the premises. Water quantity, and reliability are considered more important determinants even over water quality to facilitate practicing good hygiene habits, enjoy good health and reduce the incidence of diarrhoea (Jensen *et al.*, 2004; Clasen *et al.*, 2007; Bartram and Cairncross, 2010). These features contributed positively to the health and wellbeing of the studied population.

Improved sanitation had 95% coverage in the microcatchment. This figure was well above the coverage for rural Colombia (65%), for rural LAC (61%), and even higher than for the urban Colombia (82%) (WHO/UNICEF, 2013b). This aspect is important because sanitation represents a range of benefits from the dimensions of wellbeing as convenience, privacy, pride and comfort (Jenkins and Cairncross, 2010). Furthermore, the lack of sanitation facilities (Masangwi *et al.*, 2009; Khan *et al.*, 2013), unsafe sanitation (Bbaale, 2011), lack of ownership of a private sanitation facility (Tumwine *et al.*, 2002) have been found determinants of diarrhoea. In addition, 45% of the households in the microcatchment had access to secondary wastewater treatment systems implemented by external organizations. This is a relevant feature, since sanitation is considered an effective and efficient intervention to reduce the burden of water related diseases that can be targeted early on the chain of causation (Gentry-Shields and Bartram, 2013).

Is worth noting that the families built their toilets with their resources. In this case, the lack of demand for sanitation as a barrier for increasing access to improved systems needed to ensure human health and wellbeing, as has been reported in other contexts

(Waterkeyn and Cairncross, 2005) was not perceived. Similarly, local institutions, SU and DCC, were committed to invest in sanitation. The municipal administration recognized the importance of leveraging resources to increase coverage of secondary wastewater treatment to advance on ensuring ecosystem services downstream (Riofrio, 2012).

Another pollution source in the community was wastewater from coffee processing. Although these effluents do not influence directly on the burden of pathogens and diarrhoea, they are linked to environmental health, being a source of organic matter to water bodies when they are improperly handled (Orozco, 2003; Molina and Villatoro, 2006; Cenicafé, 2011). Some mechanisms were in place for their adequate management such as preparation of organic fertilizers, with a low level of adoption, but with potential to increase as promoted by DCC. In contrast, for animal husbandry, it was observed that there was less awareness and thus implemented alternatives to deal with this pollution source. Likewise with the adequate handling of agrochemical packages. This lack of practices and awareness may be associated to the absence of external organizations empowered to address these issues and guide the community on proper management.

In other infrastructure front, the microcatchment was poorly connected to *Riofrío* and *Tuluá*. Being a region devoted to agriculture, the adequate state of the tertiary roads was essential to allow mobilization of cargo and passengers, since most of the agricultural production was marketed in *Tuluá*. In addition, *Calabazas* inhabitants demanded public administration, health, education, security, and recreation services from urban areas, for which transport links were crucial. The inadequate state of the roads could contribute to perpetuate poverty and inadequate living conditions (Marmot *et al*., 2008). In addition, this situation could led to significant difficulties in accessing medical services, potentially increasing morbidity and mortality rates (Carabalí *et al.*, 2013).

Since most of the population were self-employed or under poor employment conditions, most of the inhabitants (85%) were insured to healthcare through the subsidized regime, and 8% were not insured. In Colombia, while the coverage of insured persons, reached a significant level (92%), 43% being in the contributive regime (Minsalud, 2013), the services provided are far from optimal. Problems of inequalities across regimes have been identified (Plaza *et al.*, 2001; Arajo *et al.*, 2011; Carabalí and Hendrickx, 2012): people under the subsidized regime have access to a less comprehensive package of benefits and is limited on its access to specialist care. In addition, lower notification rates of illnesses, hospitalizations, and confirmation of cases through specialized diagnostic have been found for the people under the subsidized regime, compared with those in the contributive (Carabalí and Hendrickx, 2012).

Despite of high health coverage figures in Colombia, coverage has not been translated into real access (Plaza *et al.*, 2001). There are access barriers including: financial, geographical, and doubts about the quality of care (Carabalí and Hendrickx, 2012). Thus, optimum conditions for service utilization have not been realized (Plaza *et al.*, 2001). While problems of inequality have been reported in Colombian cities, generally the situation in rural areas is more precarious. In the microcatchment, most population was insured but there was not real access. In *Calabazas*, as in other rural mountain villages in the world, remoteness is a barrier to improve health and wellbeing, and generates health inequalities (Kanji *et al*., 2012). Similar access barriers have been found in other remote rural areas. For example, Halvorson *et al.* (2011) reports that health seeking behaviour in Mali, was influenced by a range of costs that prevent people to look for assistance, even if free attention was provided, including: time away from livelihood activities; and transportation demands.

Insurance is an important mechanism to realise effective access to healthcare (Chau, 2010). Although a significant proportion of people in *Calabazas* was insured, the conditions of universal access, as agreed by the World Health Organization (WHO) member nations were not present, because people lacked of good quality conditions, according to needs and preferences, limited by their income level and residency (CSDH, 2008). Therefore, it is not only the presence of insurance coverage that matters regarding real access (Chau, 2010). Lack of access to good primary health care could become a condition that increases the vulnerability of the population to water-related diseases, especially during extreme events (Costello *et al.*, 2009).

In summary, it was found that for social determinants of health such as roads, education, and health care, access was poor or non-existent in real terms. In addition, the small size of farms did not allow secure income and fair livelihoods. All these factors contribute to poverty, inequality, social unrest, and to worsen the migration phenomena (Marmot *et al.*, 2008; Malik, 2013). Migration has been expressed in the demographic pattern in the area, where the proportion of the working-age population was low and the elderly high.

Furthermore, the female population was low compared to men, due to low income generating opportunities for them. As expected, in *Calabazas* the coverage of access to improved water systems was lower than the coverage in the rural areas of Colombia and LAC. However, water quantity and reliability in the microcatchment were positive characteristics that contribute to mitigate wellbeing losses and threats to health.

Surprisingly, the coverage of access to improved sanitation was well above the national and even above the urban coverage. This was an outcome of both investment of families and specific programs led by governmental and nongovernmental entities. In *Calabazas* access to water in adequate quantity at the premises and continuity, and availability of safe private systems for managing excreta could cut important paths of diarrhoea transmission.

4.4.2 Stream water quality

Water quality of *Calabazas* stream was assessed across its length to determine its status and the potential impact of land use, and anthropogenic activities over stream health, using eight parameters: flow, pH, Temperature, Conductivity, DO, BOD, TSS and TTC.

People in the microcatchment were scattered, with low density from 0.6 to 1.2 inhabitants/Ha. Coffee farms were typically less than 3 Ha, and located in an altitudinal corridor from 1300 to 1800 m. This represents smallholder agriculture in the Colombian Andes, that combines subsistence and cash crops (coffee) with grazing of cattle, occurring on small properties owned by peasants (Etter *et al*., 2006). Between 1300 m and 1000 m (the microcatchment outlet), the population was dispersed, only 10% of farms existed, most of them dedicated exclusively to livestock, with extensions between 10 and 70 Ha. This land use pattern was similar to that found by Roa-García and Brown (2009) in *Sainos*, another small rural Andean microcatchment in Valle del Cauca. They found cattle ranching, farming, poultry and pig production were the main activities, with significant differences in land use according to altitudes, the majority of cattle pasture in the lower portion of the watershed, and crops and forest in the mid and upper sections.

The microcatchment was an example of land use change processes in the Colombian Andes, in which the landscape has transformed from a biologically diverse rich forest into a biologically homogeneous landscape of mono-crops and grasslands (Giraldo, 2012). This pattern was also consistent with tropical LAC, in which the grazing area has increased over recent decades at the expense of the forested area (Rodríguez Eraso et al., 2013). This tradition of mountain colonization and agriculture production has developed on a landscape of agriculture systems interwoven with isolated fragments of natural vegetation, in which agriculture and deforestation compete between forest conservation and water provision (Giraldo, 2012).

Land use is an important factor when addressing catchment health (Aspinall and Pearson, 2000; Snyder *et al.*, 2005; Hascic and Wu, 2006; Langpap *et al.*, 2008). Agricultural activities deeply affect stream health (Brisbois *et al.*, 2008), as consequence of deforestation, intensive use of water, alteration of local biodiversity and ecosystem processes, services and water degradation (Brisbois *et al.*, 2008; Gomiero *et al.*, 2011). In the microcatchment, different documents (CVC, 1977; Loaiza, 1995; Riofrío, 2001; Riofrío, 2012) suggest land transformations altered the local environment, including the disappearance of natural forests, establishment of ranches on unsuitable lands, proliferation of untreated sewage from human settlements, and generation of agricultural impacts associated with coffee, including agrochemical use, forest loss, solid waste and wastewater. Moreover, DCC considered the degradation of water resources associated with coffee farming one of their most important concerns. In addition, CVC based on presumptive pollutant loads, listed the coffee guild as one of the greatest polluters to the great Cauca river basin (see Chapter 3). Despite all these suggestions, land use changes and anthropogenic influences did not appear to have a substantial effect over stream health in *Calabazas*, based on the results of the stream water survey.

On the other hand, temperature, precipitation, dilution, evaporation, suspension, settling, volatilization, gas exchange, adsorption/desorption, among others, provide different characteristics to water quality in different seasons (Zhang *et al.*, 2009). It is considered that seasonal variations are more pronounced in small watersheds (<100 km^2) (Bartram and Ballance, 1996), and that agricultural landscapes are more sensitive to climatic variability than natural landscapes (Leite *et al.*, 2007). However, seasonal changes did not produce significant differences over water quality in *Calabazas*.

Flow rate increased along the stream as it moved downstream with input from numerous small streams. At the outlet, average flow rates were 232.5 l/s for dry season and 429.2 l/s for rainy season. In the last section of the stream, the higher flows may be also associated with lack of forest cover, which may reduce infiltration rates and increase surface runoff (Chapman *et al.*, 1996; Maillard and Pinheiro Santos, 2008). Deforestation is an important factor over the loss of regulation of Andean mountain streams (Chará and Murgueitio, 2005). The flow in *Calabazas* had seasonal and spatial variations, contributions from *Miravalle* stream generating the biggest changes. Spatially, in the rainy season the flow had statistically significant differences between the sampling stations on the upper part (S1, S2 and S3). Whereas in dry season all sampling points had statistically significant differences. Between seasons, flow had statistically significant differences at the sampling stations in the lower part of the microcatchment (S3 and S4).

The temperature trend was similar for the two seasons. It increased with the stream length (18.0 – 22.2 °C) mainly related to the change in altitudes from 1750 to 1000 m. As expected, temperatures were higher in dry season compared to rainy season (Chapman *et al.*, 1996). The highest temperatures were recorded at the microcatchment outlet in both dry and rainy season, possibly for being located at a lower altitude, but the lack of riparian vegetation in this area could also contribute, since riparian vegetation helps maintain the thermal stability by intercepting solar radiation (Chará and Murgueitio, 2005; Maillard and Pinheiro Santos, 2008). The temperature along the stream length was in the range for natural surface waters (0° C to 30° C) (Chapman *et al*., 1996). There were spatial differences in dry and rainy season. Nevertheless, seasonally, the temperature did not show statistically significant differences between sampling points, except at the headwaters.

Regarding pH, it slightly increased from S1 to S4 (7.6 – 8.0 units). Records were higher in rainy season compared to dry season, at all sampling stations, situation that could be associated with diffuse pollution (Chapman *et al.*, 1996). However, the spatial changes in rainy season lacked statistical significance. Spatially, pH had statistically significant changes only in dry season at stations in the lower section of the catchment (S3 - S4). Furthermore, pH did not change between seasons in either of the sampling points. All the records for all stations in both seasons were within the typical range for natural waters (6.0 – 8.5 units) (Chapman *et al*., 1996).

Conductivity rose from S1 to S2, decreased from S2 to S3 and reached the highest value at S4 (117 – 165 µS/cm). Spatially, statistically significant differences were found only in dry season between each pair of successive monitoring stations. The increase from S1 to S2 was maybe due to the effect of wastewater discharges from households that were primarily coffee farms, but with diversified livelihood activities at small scale, including animal rearing (pigs, chicken, and cows). Conductivity decreased from S2 to S3, probably due to a dilution effect after receiving *Miravalle* stream, which drained from a low population density area and provided a substantial flow. At S4, conductivity reached the highest value, after receiving streams draining through mixed grazing-coffee lands, and collecting wastewater from individual sanitation systems. In general, conductivity was higher in dry season compared to rainy season at all sampling stations, which could be associated to pollution point sources which have greater effect under low flow conditions (Jamieson *et al.*, 2003; Levy *et al.*, 2009). Seasonally, conductivity did not show statistically significant differences at any of the sampling points. All the conductivity records were below a threshold value of 1,000 µS/cm suggested for polluted waters (Chapman *et al.*, 1996).

DO increased from S1 to S3 (6.5 – 7.7 mg/l), and slightly decreased at S4 (7.3 mg/l). Mean values were higher in rainy season compared to dry season, at all sampling stations, potentially linked to the higher temperatures in dry season that generally reduce DO concentrations (Chapman *et al.*, 1996). However, these spatial differences were not statistically significant for any season. In addition, there were no seasonal differences at any of the stations either. Outliers (< 5.0 mg/l) occurred in the dry season at each station, including the one that represents background water quality. These low values could be associated with coffee processing activities that occurred in the same period. However, that would not explain the low DO at the headwaters. An alternative explanation is potential problems with the samples preservation or analysis.

Most of the records, except those of the last monitoring campaign where the samples at all stations reported values below 5.0 mg/l, were within the levels considered within the range of unpolluted waters (5 - 10 mg/l) (Chapman *et al.*, 1996), the stream showing relatively high DO levels (more than 6 mg/l). Good DO levels at sampling sites of *Calabazas* indicate a high re-aeration rate and rapid aerobic oxidation of biological substances (Chapman *et al.*, 1996). These oxygenation rates may be due to the stream being fed by oxygenated tributaries and the turbulent flow regime achieved when water was flowing downstream from 1750 to 1000 m in a relatively short distance, which contributes to keep aerobic conditions.

BOD records at all monitoring stations in both season were below the detection limits of the method (< 3 mg/l), suggesting no spatial or temporal variability for BOD in the microcatchment. Natural waters with BOD values below 2.0 mg/l can be classified as unpolluted, while sources receiving wastewater may have values over 10 mg/l (Chapman *et al.*, 1996).

Median TSS increased from S1 to S3 (2.5 – 5.3 mg/l) and recovered the initial values at S4 (2.5 mg/l). Increase from S1 to S3 could originate on the impacts of land use and sanitation systems in this area. Higher flows in the lower section of the stream may contribute to dilute TSS loads. Therefore, globally, the rainy season and the large proportion of land uses like cattle raising and coffee farming in areas suitable for forest did not have the expected impact in TSS loads to the stream (Chapman *et al.*, 1996; Brisbois *et al.*, 2008; Maillard and Pinheiro Santos, 2008).

The most important water quality parameter for this investigation were TTC, because it allowed the linking of population dynamics, land use, stream health, drinking water quality and human health. There was presence of TTC in the stream even at the point that represented background water quality (S1). This situation is common in forested and mountainous areas, where wildlife contributes to the presence of bacteria (Chapman *et al*., 1996; Jamieson *et al*., 2003). In remote mountain regions, streams may contain up to 100 organisms/100 ml (Chapman *et al.*, 1996). There was a trend of moderate but consistent increase in TTC from S1 to S4 in rainy season (46 – 165 MPN/100 ml). This increase indicates that the upper and lower parts of the microcatchment contributed to diffuse microbial contamination. The increase between S1 and S2, which represents the influence of the most densely populated village may be due to small scale animal husbandry, in which animals were free to roam. When it rains, their faeces can be washed into water bodies (Jamieson *et al.*, 2003; Postel and Thompson, 2005).

The effect of the livestock zone between S3 and S4 was lower than expected, similar to results from Roa-García and Brown (2009) in *Sainos*, Valle del Cauca. Studies in rural Ecuador found that in rainy season two phenomena could operate, one of concentration of microbial pollution when the environment is heavily polluted, and one of dilution due to the greater amount of flow in the water bodies (Levy *et al.*, 2009). In this case, it is possible that the significantly higher flows in the lower part of the microcatchment, after the contributions of several streams in this last section, made the dilution effect predominates over the concentration effect attenuating microbial pollution. This moderate effect of the grazing area over microbial water quality may be also associated to the low livestock densities (see Chapter 5), the rearing system (unconfined), and the possibility that several climatic, topographic, physical, chemical and biological mechanisms (Jamieson *et al.*, 2003) contributed to a low rate of transport and survival of the bacteria from faeces´ cows to the stream. Furthermore, the spatial changes in TTC during rainy season lacked statistical significance.

According to the information expressed by the community, because there was no hydroclimatological stations in this area, the rainy season experienced during the monitoring campaigns for this research was not of the intensity as historical rainy seasons. This may be one of the reasons, that seasonal changes were not statistically significant, and potentially the impact of rainy season and diffuse pollution was not substantial.

In the dry season, TTC levels also increased from S1 to S4 (63 – 102 CFU/100 ml), but unlike the rainy season, these spatial changes had statistical significance. TTC levels between S1 and S3 (coffee zone) were different from those in the lower part between S3 and S4 (grazing zone). This behaviour may be due to a higher level of adoption of secondary domestic wastewater treatment systems and greater implementation of BMPs for handling pig faeces in the upper part compared to the lower part. Sanitation and wastewater treatment alternatives for small-scale productive activities (e.g. biodigesters, lagoons) were also noted in *Sainos* as strategies that contribute to minimize adverse effects over water quality in small Andean streams (Roa-García and Brown, 2009). In addition, the lack of riparian vegetation in the lower part, allowing access of livestock to streams in this area, that was observed during fieldwork, may increase opportunities for direct deposition of faeces (Chará and Murgueitio, 2005; Leite *et al.*, 2007; Maillard and Pinheiro Santos, 2008), which exacerbated by the lower flows in dry season (Levy *et al.*, 2009), could contribute to increase TTC in the lower part of the microcatchment. Direct animal access to the stream can affect microbial water quality more than the overall grazing intensity (Leite *et al.*, 2007).

In the case of TTC, it was not possible to determine whether there were variations at each sampling station between seasons, because different analytical methods were used in the two seasons. However, most of the records of number of organisms per 100 ml reported in both rainy and dry season were within the levels that represents lower risk of intestinal diseases, less than 100 organisms/100 ml (Chapman *et al.*, 1996). It is worth noting, that TTC are not pathogens, but an efficient and less expensive alternative to signal the potential presence of pathogens in water (WHO, 2004; von Sperling, 2007; USDA and NRCS, 2012; EPA, 2013). While the presence of TTC is a reliable index to signal the presence of pathogenic bacteria such as: *Campylobacter spp, E. coli, Salmonella spp*. and *Shigella spp*, this cannot be extended to the presence of virus or protozoa which also cause diarrhoea (WHO, 2004).

In summary, water quality showed some deterioration in relation to land use from upstream to downstream in conductivity and TTC. This decline had statistical significance for dry season, showing differences in the coffee zone (S1 - S3) with respect to the livestock zone (S3 - S4). Despite a small decline, the parameters remained at levels that characterize unpolluted water bodies. The decline could be associated with a greater number of less efficient or faulty systems for both the management of human and animal excreta, as well as the direct access of livestock to water sources in areas where riparian vegetation was removed. BOD and TSS were generally below the detection limits which levels within the ranges of low pollution. BOD and TSS were the main parameters that the Environmental Authority used to estimate the loads contributed by the polluters of water bodies in Valle del Cauca department. The low values of these parameters in *Calabazas* may suggest that strategies promoted by the DCC to encourage the adoption of ecological coffee processing and secondary domestic wastewater treatment systems could be working, together with the dilution and self-purification capacity of the source. The variation of parameters such as temperature, DO and pH was more associated with geology and topography than with land use. This coincides with the findings of Roa-García and Brown (2009) in *Sainos*.

The stream water survey yielded information, which were not available before, since it had not been monitored prior to this research. The stream resulted to be a healthy source, in line with community perceptions but in contraposition to the institutional beliefs (Chapter 3). These results, although are not generalizable, contravene the general assumption that Andean microcatchments are polluted from the upper part due to anthropogenic impacts (Vidal *et al.*, 2009; IDEAM, 2010a). The results support the potential for upstream communities of becoming providers of environmental services, such as water purification (Postel and Thompson, 2005), and contribute to make the case for monetary payments as compensations. These payments, known as Payments for Environmental Services (PES) are a mechanism to provide incentives for the adoption of more environmentally friendly alternatives, that otherwise would not be adopted (Pagiola *et al.*, 2005). In Valle del Cauca, PES are being considered by DCC as a way to supplement coffee farmers´ income (Chapter 3), and advocated by institutions interested on sustainable livestock production systems (e.g. CIPAV).

Beyond showing a case on the provision of environmental services by rural catchments (De Groot *et al.*, 2002; Pagiola *et al.*, 2005; Postel and Thompson, 2005), the results also support the view of multiple barriers for the provision of safe drinking water, and perspectives such as catchment protection, water safety plans, and water supply catchments. These perspectives consider catchment protection as the first barrier to obtain safe drinking water quality, reducing treatment costs (Lee and Schwab, 2005; Kay *et al.*, 2007; Keirle and Hayes, 2007; Confalonieri and Schuster-Wallace, 2011; Winter *et al.*, 2011; WHO, 2012a). This is important to achieve sustainability in water supply systems and to reduce risks to human health. The relationship between the state of the catchment, particularly the stream, and drinking water quality is reflected in the results presented in Section 4.3.3.

Despite the good quality of the stream, there were several aspects that deserve attention. First, the diversified livelihoods of coffee farmers, generating different kinds of pollution, for which, contrary to the case of coffee processing by-products, there were no implemented strategies, e.g. piggeries. In addition, the decline, although small, of microbial water quality in the lower part of the catchment provides grounds for the restoration of the riparian areas and the implementation of programs to help livestock farmers improve their infrastructure for the management of human and animal excreta, to sustain the achievements upstream with the programs that have benefited coffee farmers.

External support is needed to help maintaining catchment health, since many best management practices designed to reduce pollution require farm-scale interventions with associated costs, which demand integration of different sectors to cooperate (Kay *et al.*, 2007). This highlights the need for other institutions such as livestock keepers that also have levy funds to start investments in comprehensive programs to reduce the impact of their activities in rural microcatchments. For instance in New Zeeland, programmes led by the dairy industry encourage farmers to fence streams and drains (Donnison *et al.*, 2004). In Colombia, pilot programs were implemented by the Centre for research on sustainable agricultural production systems (CIPAV) to identify strategies for scaling-up sustainable livestock farming schemes, including restoration of riparian areas. However, according to staff from the Cooperative of livestock farmers for the centre and north of Valle del Cauca (Cogancevalle), CIPAV and CVC interviewed for this research, the level of adoption was extremely low and there were several challenges. For instance, not all catchments had users downstream with capacity or willingness to pay for environmental services, and in many cases, the gains upstream were offset by high levels of abstraction and pollution generated downstream (Pagiola *et al.*, 2005).

4.4.3 Drinking water quality

Water quality for human consumption in the microcatchment was explored, along with issues of water management at the community and household levels. There were four community-managed water systems covering 60% of the population. The remaining population (40%) was supplied by individual systems. Water supply alternatives were categorized as unimproved and improved systems based on the ability of the infrastructure to prevent faecal contamination to the sources (WHO, 2012b). Thus, unimproved systems were those serving individual houses, from unprotected springs or brooks; and improved systems were communal systems, abstracting water from protected springs or brooks (Acuacalabazas, Calabazas, and Acuamiravalle). Based on microbial quality and statistical tests, a third category was established, improved-D, to represent a communal water system taking water from a protected source that in addition had centralized disinfection with chlorine (Acuafenicia).

Microbial water quality increased progressively from unimproved to improved-D systems with median TTC levels around: 50 CFU/100 ml (unimproved), 35 CFU/100 ml (improved), and 0 CFU/100 ml (Improved-D). There were no statistically significant differences in microbial water quality in improved and unimproved systems between seasons. This could not be verified for Acuafenicia due to insufficient data to perform statistical tests. The findings in relation to levels of microbial contamination and category of systems are consistent with results of studies developed by WHO in 2010 in five countries that concluded that improved sources often contain faecal contamination, although at lower levels than unimproved sources, and emphasized that piped systems offer the best quality over other alternatives of improved sources (Johnston, 2013).

Improved and unimproved systems had peak TTC levels for both dry and rainy season, estimated around 2000 CFU/100 ml. Microbial water quality was variable as reflected in the standard deviations that ranged from 25 CFU/100 ml to 333 CFU/100 ml, without showing a definite trend between systems or stations. This suggests that despite low TTC values most of the time, microbial pollution pulses occurred that represented risks to human health. In this regard, Acuafenicia was different, showing low standard deviations (up to 9 CFU/100 ml) and outliers (16 CFU/100 ml) in both seasons.
The lack of statistically significant differences in microbial water quality between seasons within each category agrees with results from the stream water survey discussed in Section 4.4.2, where most water quality parameters did not show statistically significant differences from one season to another. These results are different to those from Strauch and Almedom (2011) in Tanzania and Levy *et al.* (2009) in Ecuador, who found higher microbial contamination of water sources used for domestic consumption in rainy season, associated with faecal contamination in the surrounding environment flushed to water sources due to increased runoff. As in the microcatchment, Levy *et al.* (2009) also found pulses of microbial contamination in dry season, when sporadic rains occurred.

The percentage of compliance with the water quality standard from WHO (2012a) of TTC less than 1 CFU/100 ml was for rainy season: 5% for unimproved, 0% for improved and 67% for improved-D systems. In dry season, the level of compliance was: 7% for unimproved, 5% for improved and 63% to improved-D. These results confirm that considering water as safe as expressed on the WHO standard, water from improved systems often fail to be safe. These results are similar to those from Roa-García and Brown (2009) in *Sainos*, who found that water samples taken at household water taps consistently failed to meet this standard. The results also support the widely accepted criticism on the inadequacy of the “improved/unimproved” indicator that misses the water quality dimension of access to water (Clasen, 2010; Onda *et al.*, 2012; Gentry-Shields and Bartram, 2013; Johnston, 2013). Another perspective is that the WHO standard is too restrictive and unrealistic for rural systems supplying untreated water (Jensen *et al.*, 2004; Parker *et al.*, 2010). As part of the post-2015 MDG agenda, less than 10 CFU/100 ml is considered a potential standard of an intermediate level of access to safe water (Johnston, 2013). For example, in Uganda, a medium-term standard of 50 CFU/100 ml for untreated water is used (Parker *et al.*, 2010). This could be valid for improved systems without disinfection in the microcatchment where despite the low percentage of compliance with the WHO standard, TTC levels were relatively low (< 35 CFU/100 ml).

The results of individual systems (unimproved) providing safe water, although a small proportion (5 – 7%), support calls to consider self-supply as a complementary strategy that allow countries to progress towards achieving universal access to safe water (Kumamaru *et al.*, 2011; Butterworth *et al.*, 2013; Moriarty *et al.*, 2013). It is considered that self-supply has potential in scattered rural areas, where it is expensive and technically difficult to lay communal piped systems, and for people in extreme poverty with difficulties to pay water fees (Moriarty *et al.*, 2013). However, self-supply feasibility depends on being recognized and supported by government agencies, as there are challenges about safety and reliability of water provision, and over-exploitation of limited water resources (Butterworth *et al.*, 2013; Moriarty *et al.*, 2013).

People living in the microcatchment had a good perception of drinking water quality in rainy and dry season. For users of unimproved systems, positive perception was consistent in both seasons at 81%, and for users of improved systems for rainy season was higher (78%) than for dry season (66%), possibly associated with a confusion between quality and quantity. The high levels of positive perceptions in the case of individual systems may be related to the direct involvement of families in the selection and protection of their sources. This can also operate, although at a lower level, in collective systems, where users participation in source protection activities varied from very frequent (e.g. Acuamiravalle) to scarce (e.g. Calabazas). Similar results are reported in Tanzania, in WSS managed under local traditional knowledge systems, in which good microbial water quality coincided with positive community perceptions (Strauch and Almedom, 2011).

With regards to changes in TTC levels from communal storage tanks to household taps, TTC levels decreased about almost half from the communal tanks to the households, in rainy season (42 to 24 CFU/100 ml) and dry season (40 to 28 CFU/100 ml). However, these changes lacked statistical significance. This phenomenon can be due to the decay of bacteria when competing for limited oxygen and nutrients once they are abstracted from the sources (Wright *et al.*, 2004). These results are contrary to what is commonly reported, which is microbial quality deterioration from the communal infrastructure to the houses. However, this deterioration generally occurs when limitations on the level of service demand household water storage (Jensen *et al.*, 2004; Wright *et al.*, 2004; Fewtrell *et al.*, 2005; Leiter *et al.*, 2013). In the microcatchment, water storage at the household level was relatively low (around 40%).

The four improved WSS in the microcatchment were community-managed by organizations with different levels of resources and capabilities. Community management is the model under which most of the more than 25,000 rural WSS in Colombia are run (Foster, 2005; Smits *et al.*, 2013), and it is a mechanism to address resource constraints and lack of support from higher levels (Ruano *et al.*, 2011). In the microcatchment, the community organizations enabled systems built over forty years ago to continue providing water, despite the lack of resources and external support. However, except for Acuafenicia in which the number of users allowed certain economies of scale, the other systems did not obtain enough resources to ensure compliance with legal, financial, technical and managerial standards of service provision. These results agree with Smits *et al.* (2013) from an assessment to rural community organizations running water services in Colombia. They found that only half of a sample of 40 providers performed adequately their responsibilities of internal organization, and O&M.

Lack of resources lead to several challenges for service provision in the microcatchment. Problems encountered were similar to those identified for community-managed organizations around the world: lack of external support, difficulty in carrying out replacements, low cost recovery, inadequate human resources, poor staff training (Moriarty *et al.*, 2013; Smits *et al.*, 2013), lack of information for decision making (Roa-García and Brown, 2009; Smits *et al*., 2013), leakage and microbial contamination; and at a lower level, particularly in the dry season in Acuamiravalle, intermittent supply (Lee and Schwab, 2005; Moriarty *et al.,* 2013; Smits *et al.*, 2013).

In Colombia, while different types of organizations (public, private, mixed) can run water services, legally, the final responsibility for provision rests with the municipality. In the microcatchment, community organizations developed basic O&M, with low levels of external support, and conversely felt fear of losing control over the systems due to threats of privatization. In the few cases in which support was requested to the municipality, it was to solve specific problems and provided due to influence peddling. There was no evidence of formal institutional support, operating on a regular basis offered by the municipality. This is consistent with the analysis conducted by Smits *et al.* (2013) who found that in Colombia, external support is generally provided *ad-hoc* and that many small municipalities have not implemented any mechanism to help small organizations in rural areas under their jurisdiction.

The lack of formal institutional support from the levels directly responsible (the municipality) has led to other government agencies at higher orders to assume some support tasks (Smits *et al.*, 2013). For instance, in the microcatchment, the SU had regular presence, although spaced, one visit twice a year, covering the larger systems, primarily to verify fulfilment of water quality standards. In addition, they supported the implementation of disinfection systems. However, this support program had mixed results. Centralized disinfection was effective in ensuring TTC levels below 1 CFU/100 ml, most of the time in the 500-users system (Acuafenicia). Conversely, the disinfection facilities could not be maintained in operation in the 83-users system (Acuacalabazas). In both cases, some users having small-scale productive activities depending on the water systems rejected chlorine disinfection. In Acuafenicia, this rejection was overcome because there were resources to acquire the input. In Acuacalabazas, the lack of resources and community rejection prevented engagement with the system and loss of the investment.

The disinfection program may be justified on the potential health benefits that could be achieved when access increase from an improved source to an improved source with disinfection. However, these centralized chlorination systems in rural communities may not be the best solution since: i) chlorine is ineffective to kill protozoa which also causes diarrhoea (Rosa and Clasen, 2010); ii) water can re-contaminate in the distribution network if pipes are not in good condition (Jensen *et al.*, 2004; Lee and Schwab, 2005; Onda *et al.*, 2012); iii) water can re-contaminate at homes if the service is intermittent or there is poor hygiene (Jensen *et al.*, 2004; Wright *et al.*, 2004; Fewtrell *et al.*, 2005; Leiter *et al.*, 2013); iv) people can reject the taste and smell of chlorinated water (Nagata *et al.*, 2011); iv) only a small amount of water used in rural households requires the highest microbial quality, while for the vast majority going to small-scale productive uses such as animal husbandry, growing vegetables, fish farming, and coffee processing, essential for income generation, chlorine is not required and may be harmful (Van Koppen *et al.*, 2009). Even though chlorine disinfection may not be the most effective and efficient way to improve water safety in the microcatchment context, it was the only government program offered, when there were several strategies perhaps more relevant to help these organizations. For instance, provide training on administrative and financial aspects, plumbing, O&M, or undertake investments for the replacement of infrastructure, or the acquisition of land at the headwaters.

Additionally, due to the lack of support from the government, NGOs offer some assistance to communities (Smits *et al.*, 2013). In the microcatchment, DCC was crucial in the past allowing first-time access to collective water systems. In the country, this has been criticized as a substitution of the State (Cano *et al.*, 2012). However, clearer allocation of responsibilities in the water and sanitation sector since the promulgation of the Law on Public Services in 1994 (CRC, 1994), and the coffee crisis since the 1990s have reduced DCC´s ability to invest in rural water systems. However, through international aid, DCC made efforts in sanitation and protection of water sources, contributing from the catchment perspective to water quality for human consumption. By contrast, the relation between the forestry company and the community was of conflict, failed negotiations and even accusations to control entities (see Section 4.3.3 on External support).

The case of water committees in the microcatchment, fits the general claims of *Smits et al*. (2013) who argue external support should be an integral part of community management, because the limited number of users prevent achieving economies of scale to generate the revenues to access technical and financial expertise, and these costs are high to be paid via water charges. According to Moriarty *et al*. (2013), this support is necessary in places like the microcatchment, where first-time access has been achieved and what is required is sustainable services over time, through schemes in which all aspects of service could be funded (repair, infrastructure upgrade and replacement).

The results of the drinking water quality survey, consistent with those from the stream water survey at the sampling point representing background water quality (S1), indicate that in most improved and unimproved systems, people tried to abstract water from protected sites. Despite lacking ownership of the headwaters lands, community organizations struggle to negotiate with their owners to protect sources and performed complementary activities to preserve water quality, frequently with users´ participation. Source protection was the approach in which communities relied and perceived as the alternative they had to ensure the provision of safe water, given the scarcity of economic resources. Postel and Thompson (2005) claim protection of sources is one of the most effective strategies for providing safe water, since it can result in significant reduction in capital costs and O&M. They report that costs of water treatment in the U.S. increased as systems abstract water from catchments with lower forest coverage, and provide examples of cities that avoided building expensive treatment plants after investments in catchment protection.

Relatively low percentages of water storage at the household level were found. A higher proportion of users of unimproved systems (41%) had this practice compared to users of improved systems (35%). This may be due to improved systems being supplied from more reliable sources, with less tendency to seasonal variations or dry-up, which could be more common in unimproved systems, where besides less stable sources, the infrastructure was more artisanal and prone to frequent damage. The low proportion of water household storage was a favourable aspect, which suggest that in most cases, quantity and continuity were adequate, and may contribute to reduce the chances of intra-household water contamination and to improved hygiene (Jensen *et al.*, 2004; Wright *et al.*, 2004; Clasen *et al.*, 2007; Leiter *et al.*, 2013).

In relation to Household Water Treatment (HWT), users of improved and unimproved systems had the same proportions of households developing this practice (33%). Identical results were found in a study analysing HWT based on national survey information across several countries (Rosa and Clasen, 2010). Low levels of HWT may be due to the high positive perception of people about the quality of their water (Wright *et al.*, 2004). In the microcatchment, the treatment was boiling. This may be explained because in Colombia the coverage of electricity supply in the rural areas is estimated at 92.6% (DANE, 2014a). During fieldwork it was observed that families combined electricity and wood for cooking. Therefore, the resources to undertake the practice of boiling water seem to be available. Boiling is one of the best ways to disinfect water, because is more effective against almost all infectious agents, compared with chlorine and filtration, which have limitations to eliminate protozoa and virus, respectively. However, boiling may be more expensive and environmentally harmful (Rosa and Clasen, 2010).

HWT strategies as boiling can be promoted for both improved and unimproved systems to reduce risks arising from contamination at the entire chain from the catchment to the user (Onda *et al.*, 2012). In the microcatchment, HWT could complement the strategies on sanitation and sources protection, to advance access to safe water, and minimize the hazards associated with the pulses of contamination that can occur immediately after sudden rains (Levy *et al.*, 2009; Parker *et al.*, 2010), during transport in pipelines (Lee and Schwab, 2005; Abdellah *et al.*, 2012) or in cases where water is stored at homes (Fewtrell *et al.*, 2005; Rosa and Clasen, 2010).

In summary, in the microcatchment community organizations strive to provide water services with resource constraints and lack of external support, mainly from the municipal administration. Still, due to the community efforts, the water quality offered in collective systems had relatively low levels of microbial contamination (< 35 CFU/100 ml). Furthermore, support from SU and DCC and the self-motivation of individual households that allowed considerable coverage of improved sanitation systems contributed to have a microcatchment with low microbial pollution, for which levels at individual systems were not substantially higher either (< 50 CFU/100 ml). Water in sufficient quantity, reliable supply and low proportions of storage at homes contribute to the low levels of microbial contamination. However, sporadic higher TTC levels were observed (~2000 CFU/100 ml). This highlights the importance of continue working on source protection, and the need for a multi-barrier approach involving HWT to mitigate the potential health impacts of these microbial peaks, which could go unnoticed due to the positive perception of the community about the quality of water supplied by both improved and unimproved sources.

4.4.4 Health outcomes

Diarrhoea prevalence was explored as an indicator of the microcatchment population´s health together with people´s perceptions on this disease.

Over 60% of people in the microcatchment using improved and unimproved sources indicated the risk of getting diarrhoea was low or very low, and around 80% considered the severity of an episode being high or very high. These results contrast with studies in other tropical developing countries, targeting mothers from children under 5 years old, where people perceived diarrhoea as a normal situation with low impact (Halvorson *et al.*, 2011).

Perceptions of risk influence health care seeking behaviour (Halvorson *et al.*, 2011). In Colombia, a study reported that among caregivers of children with diarrhoea, only 43% sought medical attention (CEIS, 2012). The household survey showed that none of the people who claimed to have had diarrhoea visited a health centre. The search for health care in rural areas such as *Calabazas* is limited due to access barriers. Geographic accessibility prevents access to health care (Wagstaff *et al.*, 2004; Aremu *et al.*, 2011; Halvorson *et al.*, 2011; Kanji *et al.*, 2012). Geographic accessibility includes dimensions such as distance, transport system, road infrastructure, climate and topography (Wagstaff *et al.*, 2004) that were precarious in *Calabazas*. These access barriers have consequences not only on the attention poor and vulnerable people receive, but overall on the reliability of the epidemiological surveillance system and the plans that are formulated based on it (Carabalí and Hendrickx, 2012).

Surveys for ascertaining prevalence of diseases may be used to measure health outcomes (Ansari *et al.*, 2003). This could be important when data from epidemiological surveillance fail to capture the real situation like in this case. In the microcatchment, the period prevalence of diarrhoea was 8.2%. In Colombia, although diarrhoea mortality rates have declined considerably, the trend for morbidity has increased (Manrique-Abril *et al.*, 2006). Similar tendencies are reported in other parts of the world (Ferrer *et al.*, 2008; Aremu *et al.*, 2011). In Colombia, diarrhoea is the second most common cause of morbidity (Gómez-Duarte *et al.*, 2013), and one of the most common causes of emergency, consultation and hospitalization (Minsalud, 2013).

People who got sick in *Calabazas* were women (54%) and men (46%), between 7 and 65 years. There were no reported cases in children under 5 years. The absence of cases in this age group contrasts with studies in Colombia that report a prevalence at the national level of 12.6%, with differences between regions (8.5% - 26.3%) and between urban and rural areas (11.6% - 15.2%) (Ojeda *et al.*, 2011). The results are also different to research from other developing countries. For instance, diarrhoea prevalence in a multi-country study by Esrey (1996) was 16.4%; around 15% in Uganda and Kenya (Tumwine *et al.*, 2002), 32% in Uganda (Bbaale, 2011), and 50% in Malawi (Masangwi *et al.*, 2009). This result also contravenes global estimates that consider children under five as the most vulnerable population (Black *et al.*, 2010; Fischer-Walker *et al.*, 2012). In this case the absence of cases could be for the low proportion of this age group within the studied area, 3.3%; 9% being the national figure (Ojeda *et al.*, 2011). Additionally it is possible that households with young children were aware of practicing protective behaviours as treating drinking water, breast feeding (Bbaale, 2011; Halpenny *et al.*, 2012), and adequate disposal of faeces (Ojeda *et al.*, 2011).

All the reported cases occurred in the rainy season monitoring campaign (March to May 2013), 85% the same week (beginning of April 2014). This is consistent with the seasonal behaviour of diarrhoea in Colombia, with two peaks, one from February to May (Gutiérrez *et al.*, 2005). Research elsewhere considered diarrhoea a seasonal phenomenon (Burkart *et al.*, 2011), mediated by meteorological variables (Khan *et al.*, 2013), and associated with the decrease in water quality during rainy season (Strauch and Almedom, 2011). Rainfall increases soil saturation, promotes runoff and facilitates the transport of microorganisms to water sources used for human consumption, increasing the risk of outbreaks (Curriero *et al.*, 2001; Myers and Patz, 2009; Strauch and Almedom, 2011). Diarrhoea outbreaks have been associated with peak rainfall (Levy *et al.*, 2009); after months of exceptional intense rains (Curriero *et al.*, 2001); and with precipitation during the month of the outbreak (Rizak and Hrudey, 2008).

Cases were almost equally distributed among households with access to improved (seven cases) and unimproved sources (six cases). Nine from the 13 cases occurred in houses where results from the drinking water monitoring showed TTC levels exceeding 600 CFU/100 ml. However, there were houses where TTC levels were equal or greater than 600 CFU/100 ml and diarrhoea was not reported. Different authors have found no association between drinking water quality (Jensen *et al.*, 2004) or type of water source (Tumwine *et al.*, 2002; Ferrer *et al.*, 2008; Bbaale, 2011) and diarrhoea. Other studies have found reductions in diarrhoea associated with having private taps (Masangwi *et al.*, 2009). It has been argued that lack of sufficient water is a more important risk factor than water quality over diarrhoea prevalence (Tumwine *et al.*, 2002; Jensen *et al.*, 2004; Clasen *et al.*, 2007; Halvorson *et al.*, 2011). People in the microcatchment had water supply on the premises by either individual or communal systems, and sources of supply with good amount of water most of the time, except for intense dry seasons.

Eleven cases reported not treating the drinking water, and nine cases occurred in people that perceived a low risk of getting diarrhoea. Improving microbial water quality immediately prior to consumption may be effective in reducing diarrhoea (Fewtrell *et al.*, 2005; Clasen *et al.*, 2007). In contrast, the perception of low risk can lead to poor hygiene and therefore increase the possibility of acquiring the disease (Halvorson *et al.*, 2011).

The 13 diarrhoea cases occurred in houses with improved sanitation. The high rate of access to improved sanitation in the community may have been an important factor to the relative low diarrhoea prevalence. Poor sanitation threatens contamination of water sources and may reduce the benefits associated with hygiene and water availability, and quality (VanDerslice and Briscoe, 1995; Cáceres *et al.*, 2005; Fewtrell *et al.*, 2005; Eisenberg *et al.*, 2007; Casellas *et al.*, 2012). Esrey (1996) found that "*improvements in sanitation had health impacts for diarrhoea at all levels of water supply*". Gentry-Shields and Bartram (2013) found that the most effective intervention to tackle diarrhoea was sanitation. Private ownership of sanitation facilities has been a significant determinant of the prevalence of diarrhoea in Tanzania, Uganda, Kenya (Tumwine *et al.*, 2002), and Malawi (Masangwi *et al.*, 2009). Other authors have not found associations between diarrhoea and sanitation (Ferrer *et al.*, 2008; Bbaale, 2011).

Eleven from the 13 cases were in households classified in the lowest proxy income levels (1 – 2), which agrees with what is known as the socioeconomic gradient of diarrhoea (Aremu *et al.*, 2011). In Colombia, a study found that diarrhoea prevalence in children under 5 was 16.1% for those in the lowest wealth index and 7.4% for children in the highest wealth index (Ojeda *et al.*, 2011). Being in a higher wealth status is recognized to reduce the probability of diarrhoea, especially in developing countries where most illnesses result from poverty and inequity (Victora *et al.*, 1997).

Given the few diarrhoea cases reported, it was not possible to make more than a descriptive analysis. During the research design, due to the conceptual framework, diarrhoea was selected as an indicator of human health resulting from the interactions of distal and proximal factors in the microcatchment system. It was expected that the presumed lack of formal water and sanitation, lack of institutional support, the patterns of Andean forest loss and its replacement by agroecosystems dominated by pastures, together with poverty and lack of access to health care, would contribute to a high prevalence. These assumptions were made without previous information on the study area, except for the amount of land under coffee and the general context of the rural areas of Valle del Cauca. Despite the poor behaviour of the social determinants of health, and inequalities that must be addressed, diarrhoea proved not to be a key problem to this community.

Many factors are involved at different levels on the prevalence of diarrhoea, making it a complex phenomenon (Ezzati *et al.*, 2005; Eisenberg *et al.*, 2007; Batterman *et al.*, 2009). For example, synergies between the status of water, sanitation and hygiene have resulted on different outcomes on intervention studies to reduce diarrhoea around the world (VanDerslice and Briscoe, 1995; Esrey, 1996; Gundry *et al.*, 2004; Fewtrell *et al.*, 2005; Eisenberg *et al.*, 2012). The complexity depends on interactions between the public and the private domain (Cairncross *et al.*, 1996); and as public health interventions improve access to water and sanitation, the dynamics of interpersonal transmission acquire higher preponderance (Eisenberg *et al.*, 2007; Ferrer *et al.*, 2008). The general background is the socioeconomic conditions or distal factors that influence the proximal causes of the disease (Victora *et al.*, 1997; Ezzati *et al.*, 2005).

In the microcatchment, protective factors that could contribute to low diarrhoea prevalence despite the poor performance of some social determinants of health were: environmental factors like water in sufficient quantity; infrastructure-related factors such as high coverage of improved sanitation; economic factors such as small-scale productive activities; and geographic factors such as low population density, and topography that contributed to water self-purification. These could represent system configurations and thresholds, as promoted by IWRM-EcoHealth, key to maintain systems´ resilience (Bunch *et al.*, 2011).

The results of this section are well suited to the arguments of Myers and Patz (2009), who emphasized the difficulty of finding positive association between poor health and environmental change. According to these authors, this association only exists if the following conditions are present at the same time: communities depletion or degradation of natural resources reach a threshold, and is not possible to obtain those resources outside their geographical boundaries; communities lack external support; they do not assume adaptive behaviours; and lack infrastructure. They point out people adapt to face environmental degradation, through the aforementioned strategies and therefore it is difficult to establish direct links, which instead are likely to be feedback relationships. The authors note that in this context, it is more feasible to monitor deterioration or access to resources such as food or water above infectious diseases such as diarrhoea.

Taking into account the potential for those feedback relationships between environment status and human health, a system level perspective is potentially more adequate to address risks that emerge within a causal network of multiple and interdependent processes from different dimensions (Eisenberg *et al*., 2007). The system level approach allows incorporating more distal processes into analyses, encompassing human and ecologic systems and infrastructure components (Batterman *et al*., 2009). This systemic approach is considered more useful to understand and inform the design of more sustainable interventions (Mellor *et al*., 2012). Chapter 5 uses System Dynamics Modelling (SDM) to establish connections between the socioeconomic and environmental factors over human health and wellbeing, using diarrhoea prevalence as a health outcome to increase understanding of catchment and human health and wellbeing in *Calabazas*.

4.5 Conclusions

This chapter addressed the issue of catchment health and human health and wellbeing in a rural Andean community, from a holistic perspective, including distal and proximal factors, several levels of analysis, and considering the conceptual framework of IWRM-EcoHealth (Parkes *et al.*, 2010; Bunch *et al.*, 2011). Health outcomes were focused on diarrhoea prevalence.

The results contribute to fill a gap on reliable, fine-scaled, geo-referenced data about socioeconomic indicators, land use, concentrations of bacteria indicators in-stream and drinking water sources, water and sanitation infrastructure, governance, and diarrhoea prevalence, among others (Myers and Patz, 2009). The study case represents a rural area that exemplifies the diversity of the Colombian countryside. Information on indicators from different dimensions across regions contribute to discover the most pressing issues experienced by rural communities. Information on these contextual factors associated with human health and wellbeing, allow designing policy and interventions tailored to the needs of different regions (Wilcox and Kueffer, 2008; Bbaale, 2011). Rural regions are diverse and different to urban areas for which different approaches are necessary and complementary to address the welfare gap, caused by the lack of investment in the countryside and the transfer of solutions designed for urban settings to rural contexts.

Results from the household survey showed that several of the conditions experienced in relation to the social determinants of health in *Calabazas* fit to the calls of the international community to improve the situation in rural areas. Among them, the need to improve access to land, credit and extension services, farmers´ income, together with investments in pro-poor interventions such as roads, access to health, and education (Marmot *et al.*, 2008; Kanji *et al.*, 2012; Malik, 2013).

The stream water survey proved that *Calabazas* was a healthy stream, provider of environmental services such as good water quality for users downstream, thus with potential to implement PES to progress on environmental protection and as an alternative source of income for farmers (Postel and Thompson, 2005). This research provided information on the links between land uses and water quality, filling a gap on information in these linkages, considered a limiting factor to design institutional mechanisms for PES (Pagiola *et al.*, 2005). The results also support the view of multiple barriers to ensure the safety of drinking water, and approaches such as catchment protection, water safety plans, and water supply catchments, as a core strategy to deliver safe water, improve determinants of human health, keep ecosystems integrity, and enhance sustainable livelihoods (Bunch *et al.*, 2011).

The information presented contributes to the current debate about progress on the 7c target of the Millennium Development Goals (MDGs) and the Post 2015 agenda on access to water. Recent studies at global level (Onda *et al.*, 2012) indicate that when using the WHO standard of less than 1 CFU/100 ml, access to safe water figures reduced compared to figures when the improved systems indicator is considered. The latter indicator overestimates access to safe water by about 1.2 billion people in the world, and therefore underestimates the real effort required to achieve the MDG target (Onda *et al.*, 2012). In *Calabazas*, while 60% of the population had access to improved systems, only the 24% of users from Acuafenicia had access to water with less than 1 CFU/100 ml, most of the time. These results suggest the need to revise the figures for access to safe water in Colombia, as is being done in different parts of the world (e.g. Godfrey *et al.* (2011)), to involve aspects of quality and define the orientation of the water sector investments. Another route will be considering a differentiated approach to undertake access to water for rural areas, considering more flexible medium-term quality standards for systems without treatment, more attainable for community-managed organizations (Jensen *et al.*, 2004; Parker *et al.*, 2010), and catering for the multidimensional water needs of rural people (Van Koppen *et al.*, 2009).

Results from this research provide grounds for the design and implementation of programmes for the water sector in Colombia to reduce the gap on access to safe water in the rural areas. In many rural areas, access to safe water depends on the capacities of local communities to maintain the environment's ability to deliver services (Walker *et al*., 2001). This research provides evidence on the need to design municipal schemes to back communal water committees, given that is widely recognized that despite their efforts, community organizations require external support to ensure the reliability and quality of services over time (Moriarty *et al.*, 2013; Smits *et al.*, 2013).

The results question the implementation of centralized disinfection systems as the best alternative for accessing to safe water in rural areas of Colombia, considering all the possibilities for re-contamination from treatment systems to the point of use (Rosa and Clasen, 2010), and given the generally higher proportions of households engaged in small-scale productive activities dependent on water from collective systems (Roa-García and Brown, 2009; Van Koppen *et al*., 2009; Domínguez *et al*., 2014). Conversely, increasing sanitation coverage, protection of sources, improving networks, and HWT for the small fraction of water used for drinking and cooking may be more sensible choices in contexts such as the microcatchment, where microbial contamination does not exceed most of the time 50 CFU/100 ml. Measures to reduce the risk of contamination when pulses are present should be incorporated.

The findings endorse the consideration of alternative approaches for water provision in rural areas such as self-supply (Kumamaru *et al.*, 2011; Butterworth *et al.*, 2013; Moriarty *et al.*, 2013). The self-supply approach being promoted takes advantage of the families´ motivation to invest on their water systems, but is recognized and supported by government agencies. The support will be focused on identifying low cost measures and behavioural changes, incorporating a multiple-barrier approach to incrementally progress access to safe water (Butterworth *et al.*, 2013). In Colombia, individual systems are not recognized as a potential alternative to supply safe water. In this region, there are scattered areas with difficult topography, abundant and relative good water quality, which would benefit from the development and transfer of packages for the design, construction and O&M of water supply systems for individual households, encompassing multiple uses of water.

Although diarrhoea was not a major health issue in *Calabazas*, in Colombia it is estimated that each year about 1.5 million episodes occur, with between 60,000 and 90,000 hospitalizations (De la Hoz *et al.*, 2010). This study provides evidence that sanitation is a key strategy to implement in rural communities to reduce diarrhoea prevalence and in general improve human health. Access to sanitation is not a priority for the Colombian government to invest in rural areas, where the current emphasis is providing collective water infrastructure. The study also shows how as progress is achieved through different strategies, such as increase in sanitation coverage, risk factors change and other interventions to further improve people´s wellbeing are required (Ferrer *et al.*, 2008).

This research included in the sample population a variety of people spread across the study area, even those located in households of difficult access. Usually for security, logistic and budgetary reasons those people are considered hard to reach, and not included in research or development initiatives. This was possible mainly with the committed participation of community leaders and the use of different means of transportation: foot, horses, motorcycles and four-wheel drive cars. Another strength was conducting monitoring campaigns in dry and rainy season, and taken together with parameters of microbial contamination, parameters that provided a broader view of stream water quality. Furthermore, the study considered a relatively high density of sampling points for a small catchment, which allowed to report details of the sections in which the most significant changes occurred. Having the microcatchment as analysis unit allowed understanding drinking water quality in collective and individual systems, within the context of land use and sanitation. In addition, water quality was assessed at all existent collective systems regardless of size, and to a statistically representative sample of individual systems.

4.5.1 Limitations

The limitations in this component of the research included:

- The need to change the laboratory responsible for analysing the samples for the stream water survey from the rainy season to the dry season. This change involved a methodological change to analyse TTC from the Most Probable Number to Membrane Filtration. This change meant that data for TTC was analysed separately each season, and that between seasons only was possible to compare trends and not magnitudes.

- Financial restrictions implied the sampling period was limited to eight campaigns, covering one rainy and one dry season. Although this strategy provided adequate information to the level of detail sought, some authors recommend monitoring periods that extend for at least one year (Levy *et al.*, 2009). In this case, longer monitoring campaigns would provide more conclusive results on the effects of activities associated to coffee farming (e.g. fertilization and processing), the impact of BMPs implementation over stream quality, the influence of the rainy season over diffuse pollution, and seasonal changes in drinking water quality.

- The study collected data on livestock density and the level of confinement, but did not delve into issues such as the amount of time animals spend in confinement, in pastoral areas and drinking water in the streams. This information improves characterization of microbial pollution sources in agricultural catchments (Jamieson *et al.,* 2003).

- Although few families from Acuafenicia participated in the research, the denial by most users and their water committee implied this system was underrepresented. Rejection was due to mistrust that could not be overcome and that originates from a history of violence in the area. In addition, the research was associated to potential water privatization and even community leaders supporting the study were threatened to be responsible in the event of a privatization. This situation highlights the challenges of working in rural areas of Colombia where there are sequels or armed conflict persists.

- The analysis of diarrhoea used a self-reported 15-day recall period. Recall periods greater than 48 hours have been considered likely to reduce the reported cases (Gundry *et al.*, 2004; Clasen *et al.*, 2005; Aremu *et al.*, 2011).

- The relatively small sample due to the size of the community, its dispersion, and the difficulty to visit more homes due to the capacity of the equipment to process microbial water quality, limited the number of households to visit and therefore people asked about diarrhoea episodes. A small sample size has been a limitation reported in other studies (Jensen *et al.*, 2004), as a potential reason to found no statistically significant associations between water quality and diarrhoea.

- Selecting as study case a place in which human health was not compromised, as originally thought, was another limitation. *Calabazas* was selected because it was one of the microcatchments where DCC had presence with PFP. Selecting a site with higher diarrhoea prevalence may have been a more interesting case. However, it was unlikely to have preliminary information on the health situation in any of the Andean rural microcatchments of Valle del Cauca department that would have improved the selection of a more relevant case.

Chapter 5. Participatory model

5.1 Introduction

In rural catchments of developing countries, precarious livelihoods, deficient access to health care and education, land use change, microbial pollution, inadequate sanitation, access to water of poor quality and lack of institutional support are common problems, which affect poor and vulnerable people. Different authors have advocated for broader perspectives to address the linkages between environmental health and human health and wellbeing, focusing on developing countries. Ezzati *et al.* (2005) argue that exposure to environmental risks depends on multiple determinants, which are interrelated through a "causal web" that includes a continuum of distal, proximal, and physiological and patho-physiological causes, which lead to disease outcomes, and emphasize on the consideration of socioeconomic aspects. Batterman *et al.* (2009) promote interdisciplinarity and a systems approach to facilitate the analysis and understanding of interactions and feedbacks to find sustainable solutions to control water-related diseases. Parkes *et al.* (2010) argue for an integration between IWRM and EcoHealth as a strategy to fulfil overlapping objectives between human health and environmental management, through consideration of ecosystems, health and wellbeing, and social dimensions, having the catchment as the "ideal" analysis unit (Parkes *et al.*, 2010; Bunch *et al.*, 2011).

This advocated broader perspective demands a more holistic and interdisciplinary approach to enquiry, problem identification, analysis, and solution (Eisenberg *et al.*, 2007; Batterman *et al.*, 2009; Parkes *et al.*, 2010), and posed the challenge of integrating data collection and analysis of multiple variables to account for linkages across the dimensions involved (Ezzati *et al.*, 2005; Batterman *et al.*, 2009; Eisenberg *et al.*, 2012).

IWRM, EcoHealth and their integration are ecosystem based approaches in which systems thinking can provide frameworks and tools to facilitate understanding of the relations between elements of diverse nature in the complex socio-ecological systems they deal with (Forget and Lebel, 2001; Bunch, 2003; Charron, 2012).

Systems thinking is a transdisciplinary field, which provides a specialized language and tools that help to understand complex problems (Sterman, 1994). System Dynamics (SD) is one branch within the systems thinking approach that uses qualitative and quantitative modelling tools to reveal and understand system´s behaviour, communicate with others about this understanding, and design high-leverage interventions (Hjorth and Bagheri, 2006; Richardson, 2011; Mirchi *et al.*, 2012). Qualitative tools are useful for problem description (Mirchi *et al.*, 2012), and quantitative models include equations describing dynamic change, assumptions, and allow simulations to analyse system performance under different scenarios (Winz *et al.*, 2009).

SD has been widely used in Water Resource Management (WRM) to help increase understanding on the interdependent ecological, social and economic systems, that pose challenges for effective decision making (Wang *et al.*, 2011). Extensive reviews about applications of SD in WRM can be found in Winz *et al.* (2009) and Mirchi *et al.* (2012).

SD models that use the catchment as system boundary could be categorized in four topics: i) balancing water supply and demand, ii) hydrological processes, iii) water pollution with nutrients, and iv) socioeconomic issues over watershed management. The fourth category includes models addressing linkages between social, economic and technical issues more in line with the premises of IWRM, and looks at the impact of socioeconomic drivers over environmental pollution to support decision-making (Guo *et al.*, 2001; Payraudeau *et al.*, 2002; Yu *et al.*, 2003; Chen *et al.*, 2005; Kashimbiri *et al.*, 2005; Kato, 2005; Leiwen *et al.*, 2005; Leal Neto *et al.*, 2006; Odada *et al.*, 2009; Qin *et al.*, 2011; Venkatesan *et al.*, 2011). However these models typically overlook how environmental pollution influences human health and wellbeing.

SD has not been explicitly used in EcoHealth. Research in EcoHealth uses different units of analysis: urban areas (Spiegel *et al.*, 2003; Waltner-Toews and Kay, 2005; Juarez *et al.*, 2008; Quintero *et al.*, 2009), rural areas (Rojas-De-Arias, 2001) and catchments (Parkes *et al.*, 2004). Work focuses on the effects of environmental changes on particular diseases. For instance, the effect of land use change on populations of vectors of dengue (Quintero *et al.*, 2009), and on dengue transmission (Vanwambeke *et al.*, 2007); livestock intensification and *Campylobacterosis* (Parkes *et al.*, 2004). Other studies concentrated on sociocultural aspects of diseases, embedded in the ecological context (Juarez *et al.*, 2008; Quintero *et al.*, 2009).

Methodologies commonly involve building conceptual frameworks to understand the linkages between the aspects considered. Data collection methods include aerial photographs and land use maps (Parkes *et al.*, 2004; Vanwambeke *et al.*, 2007), collection of samples of vectors (Vanwambeke *et al.*, 2007; Quintero *et al.*, 2009), water (Parkes *et al.*, 2004; Juarez *et al.*, 2008), or blood (Vanwambeke *et al.*, 2007); household surveys to identify socioeconomic determinants of environmental change and diseases (Parkes *et al.*, 2004; Neudoerffer *et al.*, 2005; Vanwambeke *et al.*, 2007; Juarez *et al.*, 2008; Quintero *et al.*, 2009); qualitative methods such as in-depth interviews and focus groups (Parkes *et al.*, 2004; Neudoerffer *et al.*, 2005; Quintero *et al.*, 2009); and collection of epidemiological information from secondary sources (Parkes *et al.*, 2004; Neudoerffer *et al.*, 2005; Vanwambeke *et al.*, 2007).

Results are frequently statistical models or analysis establishing relationships between environmental and/or socio-economic factors and health outcomes such as vector abundance, risk of infection or disease (Parkes *et al.*, 2004; Vanwambeke *et al.*, 2007; Juarez *et al.*, 2008; Quintero *et al.*, 2009); improved understanding on vector epidemiology, ecology or molecular genetics (Parkes *et al.*, 2004); and description of potential interventions to break the pathogen transmission cycle (Parkes *et al.*, 2004). The work by Neudoerffer *et al.* (2005) on *Cystic echinococcosis* in a ward in Kathmandu, uses diagrams to integrate the information gathered from different data collection strategies. They used narratives about the current situation elicited from stakeholders, and explored causal structures from various perspectives and synthetized these into diagrams, based on systems thinking tools from the soft systems theory by Checkland (1999). The process allowed community members and research scholars to understand their eco-social system for problem solving and learning (Neudoerffer *et al.*, 2005). This experience is closer to the qualitative aspect of Mediated Modelling (MM) in SD, but this approach does not provide the opportunities for quantification offered by SD.

No previous examples of use of SD for integrated IWRM-EcoHealth analysis have been found. However, there is research in SD addressing broadly water and health issues. Different scales are used: the world (Simonovic, 2002); insular towns (Moreno *et al.*, 2004); catchments (Cox, 2005); rural communities (Degoma *et al.*, 1979), regions (McKnight *et al.*, 2010), old industrial sites (Vishnevsky *et al.*, 2011), and coalfields (Vizayakumar and Mohapatra, 1992). Cox (2005) selected the catchment as the spatial scale for his model. This model assessed the potential impacts of changes in coastal water ways in Australia over human quality of life and established relationships between: population growth, water quality, vegetation and biota; bacteria indicator concentrations, gastrointestinal illness; bacterial and heavy metal contamination of oyster leads; and perceived waterway conditions. However, this study did not report on the methodology used, information sources or input from stakeholders.

This Chapter describes a modelling process in which staff from the Departmental Coffee Committee (DCC), and later a broader stakeholder base, participated in developing a semi-quantitative SD model, using the Stella 10.0 software. The developed model consists of socioeconomic and environmental factors, which are measurable indicators of key aspects relevant to understand human health and catchment health in the study microcatchment. The factors are linked together depicting relationships, with dimensional consistency. The behaviour of most of the factors or their initial value for the year 2013 was established, either through collection of primary or secondary data, consultation with stakeholders, or triangulation of the different information sources. However, limitations on the availability of historical information for the factors and lack of understanding of key relationships between these factors in the study catchment did not justify to write dynamic equations. Therefore, the model is mainly conceptual, and it does not perform simulations.

This chapter reports on the use of SD as a methodology that could be incorporated to the toolkit of IWRM-EcoHealth. In this research, SD was used to integrate knowledge from a diverse group of stakeholders to improve understanding on the relationships between catchment health and human health and wellbeing, taking diarrhoeal disease as a health outcome in *Calabazas* microcatchment.

The structure of this chapter comprises four sections. First, the methodology is presented including a description of the software, followed by explanation of the qualitative and quantitative data collection strategies adopted, and the integration and synthesis using SD. Second, the model is described as the outcome from the process. Third, a discussion focused on the system´s understanding is presented. Finally, conclusions are outlined.

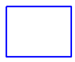
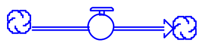
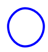
5.2 Methodology

Relationships between socioeconomic and environmental factors, related to catchment health and human health and wellbeing in *Calabazas* were conceptualised using participatory strategies (Vennix, 1999; Van den Belt, 2004). This section includes a brief description of the Stella software, program used for building the SD model, and an explanation of the data collection and analysis methods used. The methods included: semi-structured interviews, focus groups, and collection of primary and secondary information. The model was used for integration, triangulation, synthesis and analysis of the collected information.

5.2.1 The Stella software

Stella is one of the software packages available to develop SD models. This software provides a set of graphical objects with their mathematical functions to facilitate representing system structure and developing computer code (Costanza and Ruth, 1998; Tidwell *et al.*, 2004; Van den Belt, 2004; Wang *et al.*, 2011; Mirchi *et al.*, 2012). SD models produced with Stella are built from four basic objects: stocks, flows, converters and connectors (Table 5-1).

Table 5-1 Stella system components and their modelling symbols

Name	Description	Symbol
Stock	A component of a system where something is accumulated	
Flow	Activities that determine the values of reservoirs over time.	
Converter	System quantities that dictate the rates at which the processes operate and the reservoirs change	
Connector	Defines cause – effect relationships between system elements	

Deaton (2000)

Stocks and flows are the building blocks of the model (Chen and Wei, 2014). Stocks are the key variables that represent accumulation or storage in the system (Venkatesan *et al.*, 2011). Examples of Stocks include population, biomass, nutrients, or money (Costanza and Gottlieb, 1998). Flows represent processes or activities that increase or reduce Stocks´ levels (Venkatesan *et al.*, 2011). The value of each flow is the amount of change it causes in the Stock per unit of time (Deaton, 2000). Clouds at the end of flow structures are undefined sources and sinks (Costanza and Gottlieb, 1998). Converters represent relationships between system´s components and have a variety of roles within the structure. They can dictate the rates at which the flows operate; or represent ratios, proportions, constants, mathematical, graphical functions, or data sets (Costanza and Ruth, 1998; Deaton, 2000; Elshorbagy and Ormsbee, 2006; Venkatesan *et al.*, 2011). Connectors are single arrows, used to establish relationships between variables. They show the flow of information and depict cause-effect relationships between system´s components (Deaton, 2000; Venkatesan *et al.*, 2011).

All these objects and their relationships constitute the model structure. To facilitate building the structure, the model can be divided in sectors, connected through objects called ghosts (Figure 5-1).

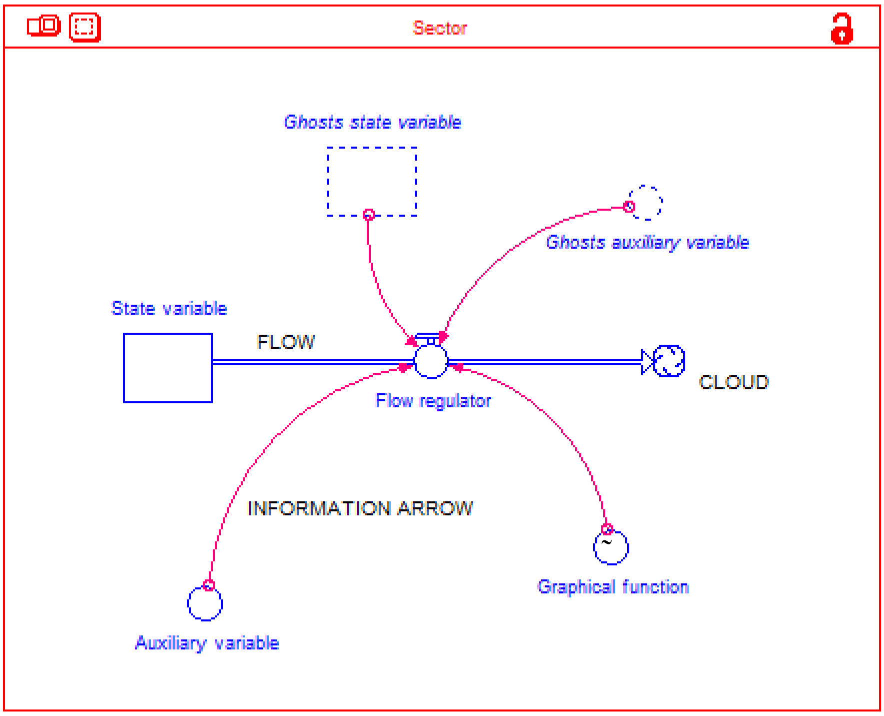


Figure 5-1 Representation of a model sector and its components

Adapted from: Costanza and Gottlieb (1998)

Identifying key variables, representing them, building the model structure, developing mathematical functions and simulating the model are the main steps in building SD models (Elshorbagy and Ormsbee, 2006). Models developed through participatory process are normally carried out at scoping level. These are high-generality, low resolution and consensus building models, involving broad representation of stakeholder groups affected by the problem (Costanza and Ruth, 1998; Van den Belt, 2004).

The next section presents the methodology developed to produce a scoping model to link catchment health and human health and wellbeing in *Calabazas*, under the conceptual framework of IWRM-EcoHealth, using SD tools and the Stella software.

5.2.2 First round of semi-structured interviews

Stakeholders´ perceptions, concerns and knowledge (mental models), are the base of participatory SD models (Vennix, 1999; Van den Belt, 2004). The stakeholders´ mental models, and the Causal Loop Diagram (CLD) prepared from them (Chapter 3), were the inputs to produce a preliminary model using Stella 10.0.

The preliminary model was used to show to the gatekeeper at DCC the type of output that could be obtained from the process, increase his interest on the participatory strategy, and was the starting point for defining the model building work through focus groups. The gatekeeper suggested an approach of one plenary meeting and then an agenda to work individually with the participants, according to the model needs, and time availability of the individuals in the group.

5.2.3 Series of focus Groups

The focus groups for model preparation followed initially the Group Model Building (GMB) methodology (Vennix, 1999; Andersen *et al.*, 2007), the DCC being the customer, since the initial research idea emerged looking to integrate the student´s interests with those from DCC. The base group for the process was relevant staff from DCC. These stakeholders were selected using a snowballing approach, starting with the gatekeeper. From November 2012 to December 2012, three focus group sessions for model building were carried out at the DCC offices in Cali, as explained below:

First meeting

The first meeting was arranged directly by the gatekeeper inviting his collaborators. The people invited were staff from DCC linked to Peace Footprints Project (PFP) (Chapter 3). Dr Ines Restrepo, the local PhD supervisor from Universidad del Valle, was invited to perform a facilitation role. Paola Chaves, a social communicator and Master in Environmental conflicts, was invited as note-keeper.

In preparation for the meeting, a detailed script (Andersen and Richardson, 1997) was written and shared with Dr Restrepo and Paola Chaves. The script provided them background on the research and their roles during the meeting. It was also useful for planning the meeting and ensuring the objectives were met. The script included background information about the history of the collaboration project, the PFP, and the PhD research with a focus on the participatory modelling methodology. The script comprised: meeting objectives, agenda, list of participants and their backgrounds; detailed account of how each section in the agenda should evolve; and explanations of the facilitator team roles. The agenda for the first meeting is shown in Appendix I. The first meeting was carried out on the 22th of November 2012, and all the people invited attended. The agenda was conducted according to plan. The participants worked on an envisioning exercise on which they wrote in pieces of paper what would be a healthy catchment with healthy people. The contributions were organized in a flipchart according to topics that provided the model sectors. Relations were drawn between the factors in the papers. In parallel, the researcher drew model sectors, stocks, flows and converters using the software, according to the development of a discussion led by Dr Restrepo. The meeting was recorded and notes were taken. At the end, the meeting achievements were summarized and a date for a new meeting was agreed (Figure 5-2).

Second meeting

The second meeting was held on the 29th of November 2012. The purpose of this meeting was to review and improve the model structure developed in the first meeting. About 1.5 hours were allocated to discuss three model sectors, and the model structure was improved with feedback from the participants. After the time allowed concluded, a new meeting was defined to continue working with the sectors of the model that were not discussed at this meeting. This time, the author facilitated the meeting and performed the modeller role. Paola Chaves took notes.

Figure 5-2 First focus group for modelling

Third meeting

The third meeting took place on the 3rd of December 2012. After recapitulation of the progress made, model sectors that were not addressed in the previous meeting were revised and improved. During this meeting, gaps in sectors of the model in which the group did not have sufficient knowledge, such as the health sector, were identified, and thus the need to seek help outside the group to improve them. Individual meetings with the participants were scheduled to work in specific areas in the model and collect secondary information available to progress in quantification.

Primary data collection activities that complemented the focus groups and the collection of secondary information were discussed. These activities involved the surveys detailed in Chapter 4. These surveys were intended to gather information on aspects where no secondary information at the microcatchment scale was available. Mechanisms to keep communication to review progress in model development were agreed.

These meetings lasted around three hours. After each meeting, results from the discussions were organized. The recordings were reproduced, and notes were prepared in Word 2010 as descriptive accounts. The stocks and flows diagram in Stella was improved as an outcome from each meeting. A summary with the details about the three focus groups is provided in Appendix J.

5.2.4 Collection of secondary information

Data available from government agencies, organizations, maps and charts, and survey data previously collected for purposes different to the present research were gathered. Secondary information was searched for each model parameter (stocks, flows, and converters). The emphasis was in existing economic, hydrological, climatic, environmental, health, agriculture, demographics, quality of life, and diarrhoea, among others. The information was collected at any available scale: country, department, municipality, catchment, and microcatchment. Historical information was gathered to the available date.

Data on model parameters were retrieved from institutional websites, during interviews with stakeholders, or formally requested to organizations. Graphs, tables, or time series were prepared, if possible, for each model parameter based on the secondary sources. Otherwise, factors, ratios or any data that served for quantification were captured, as well as descriptions of the aspects in consideration, where available. Secondary information also served to assess if the emerging patterns were common to other rural areas in the Colombian Andes. This information appears for each model sector in diagrams showing model structure and on tables showing values for the parameters corresponding to the year 2013. This information appears with the code CSI that indicates data were obtained from Collection of Secondary Information. Sources of secondary information checked at different scales are shown in Appendix K.

5.2.5 Collection of primary information

Primary information on model parameters not available from the institutions with presence in the area was collected through three surveys described in Chapter 4. Results from these surveys were processed and fed as quantitative data on model parameters. For instance, as initial conditions for stocks such as population of humans, pigs, or livestock; or as converters: average coffee farm, average livestock farm; coverage of improved water and sanitation, among others. This information appears for each model sector in diagrams showing model structure and on tables showing values for the parameters corresponding to the year 2013. This information in both diagrams and tables, appears with the code CPI, which indicates data were obtained from Collection of Primary Information. These results were useful to describe model parameters and their behaviour in the study area.

5.2.6 *Second round of semi-structured interviews*

From December 2012 to January 2014, 24 interviews with people from institutions and community were carried out to discuss model structure and progress on quantification. In these meetings, the model was presented on the computer screen with the Stella software, and then the particular section of the model in which the interviewee had expertise was widely discussed. Interview guides were not prepared. The previous day, the gap to be filled with the interview was checked, that sector of the model printed, and the prints were used to discuss with the interviewee the aspects of interest. During these sessions, the interviewee suggested changes or approved the model structure presented, provided data from his/her knowledge or expertise on model parameters, contextual information, or relevant documents.

Data given by the stakeholders to progress on quantification appears in tables and diagrams presented for each model sector. These data have been coded as a primary source (CPI) or assumed (A). It has been considered a primary source when it relates to existent unpublished data (e.g. investments in individual sanitation systems) and assumed when it is the result of experience or knowledge of stakeholders on the aspect in consideration (e.g. yield of coffee plantations).

During the interviews, notes were taken and the required changes to the model structure on the sectors printed in paper were made. Then, these changes were reproduced in the computer model. If respondents allowed, the interviews were recorded and transcribed. The information provided was included in a draft model description document.

Due to knowledge fragmentation, interviewees recommended to meet other people and provided contact details. These meetings were held until there were no more recommendations to see new people. Appendix L shows a list of these second round semi-structured interviews and Figure 5-3 includes a diagram showing participants in model construction through either individual or group modelling sessions. Participants were people from nine institutions, at the microcatchment, municipal and departmental scale, from a wide range of backgrounds and specialities. Each oval represents one participant, and its colour, the affiliation. The direction of the arrows shows the referencing paths.

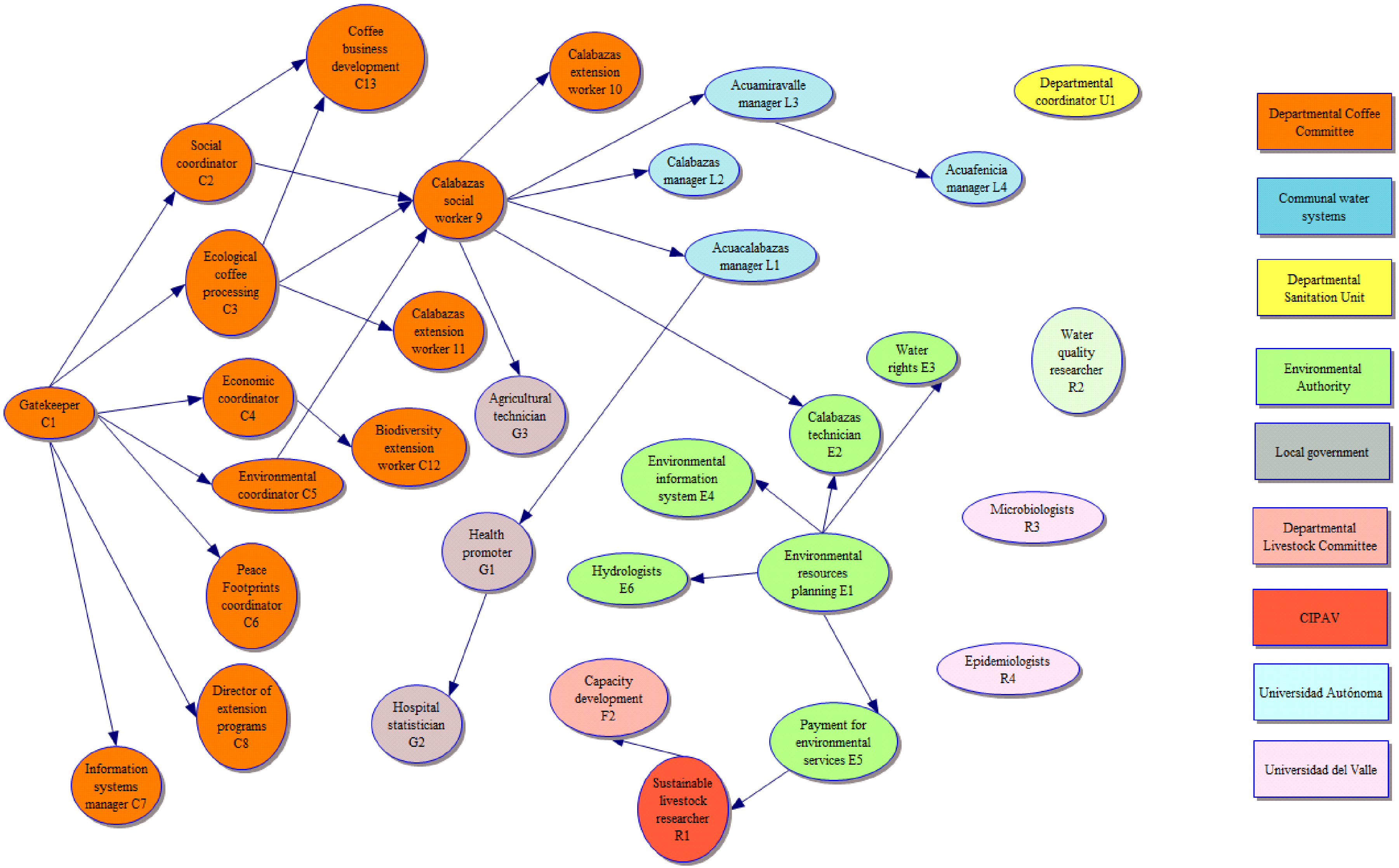


Figure 5-3 Stakeholders referencing paths

5.2.7 Triangulation and synthesis

SD principles and the Stella software were used to integrate the information collected through the primary and secondary sources described above to build a semi-quantitative model that included components of diverse nature at multiple scales, linking environmental health and human health and wellbeing in the case study microcatchment.

The model was a strategy for knowledge integration, which complemented the methodological triangulation introduced in the research with the use of qualitative and quantitative methods and the analysis of the information collected through them.

The information gathered through the different strategies was used to describe different model sectors: population, economic, land use, stream health, human health and management. To reduce complexity some sectors were divided into modules. For example, the stream health sector was divided into three modules: BOD (Biochemical Oxygen Demand), TSS (Total Suspended Solids) and TCC (Thermotolerant Coliforms). Each model sector was described and synthesized through a diagram build on the Stella software and a table. The diagrams show the different factors that compose the system structure, represented by storages, converters, flows and connections between them, the objects that made the software language. Tables provide another visual summary for each model sector. Both, diagrams and tables present the factors accompanied by data on their quantitative values for the year 2013. These data are shown together with codes that indicate the source of information as follows:

- CPI: data from primary sources, obtained as a result of this investigation using the methods discussed in Section 5.2.5
- CSI: data from secondary sources, obtained as explained in Section 5.2.4 (with reference to the end of each table)
- A: data assumed after considering literature sources, discussion with stakeholders through individual meetings, focus groups or both (see Section 5.2.6)
- E: data estimated from other model parameters by computing simple operations. The equations used to obtain these values are included in Appendix M.

The next section presents the results obtained from the use of this methodology, describing the sectors that comprise the produced systemic model, which links catchment health and human health in *Calabazas*.

5.3 Results

For the PhD, the goal of developing the model was to identify whether through a participatory methodology, using SD, socioeconomic and environmental factors could be linked, to improve understanding of the relationships between catchment health and human health and wellbeing at the microcatchment scale. For DCC, the goal was to have a tool that allowed them to make more tangible their focus on sustainability, stated in policies, documents, and implemented through various programs, and particularly, to have a tool to “integrate” the elements involved in their approach to management having microcatchments as administrative boundaries. From their point of view, all their interventions should be reflected in better performance of key indicators at the catchment scale (e.g. Q2, Q3, and Q22 in Chapter 3). As a strategy to combine these two goals, the participatory process of building the model was developed. As part of the discussion with DCC staff in the first focus group meeting (see Appendix I and Appendix J), the group selected the ideas to explore using modelling. These ideas were:

- Coffee growing is not profitable and wellbeing of farmers is threatened
- If coffee farming is not profitable neither the National Coffee Fund (FoNC) nor the farmers have resources to invest in more sustainable ways of interacting with the environment
- The coffee industry generates a significant impact over water resources
- Livestock farming generates risk factors for diarrhoea prevalence
- Interventions by DCC have a positive impact on different dimensions of farmers´ wellbeing which are reflected at the microcatchment scale.

With these ideas in mind, the time step of the model was agreed as one year, and the spatial scale, the microcatchment to match with the administrative unit adopted by DCC. The level of spatial explicitness was homogeneous, this means that only average values for the factors at the microcatchment scale were included and thus, spatial changes in the factors at different areas in the microcatchment were not considered. The model was intended to integrate social, economic and environmental issues. Thus, the resultant model sectors were: i) population, ii) land use, iii) economic, iv) stream health, v) human health, and vi) management (Figure 5-4). These sectors emerged from the focus groups meetings. The division of the model in sectors facilitated the group to address the modelling tasks in stages and in a structured manner, and allowed in the second round of semi-structured interviews, communicate with people according to the level of expertise in particular areas.

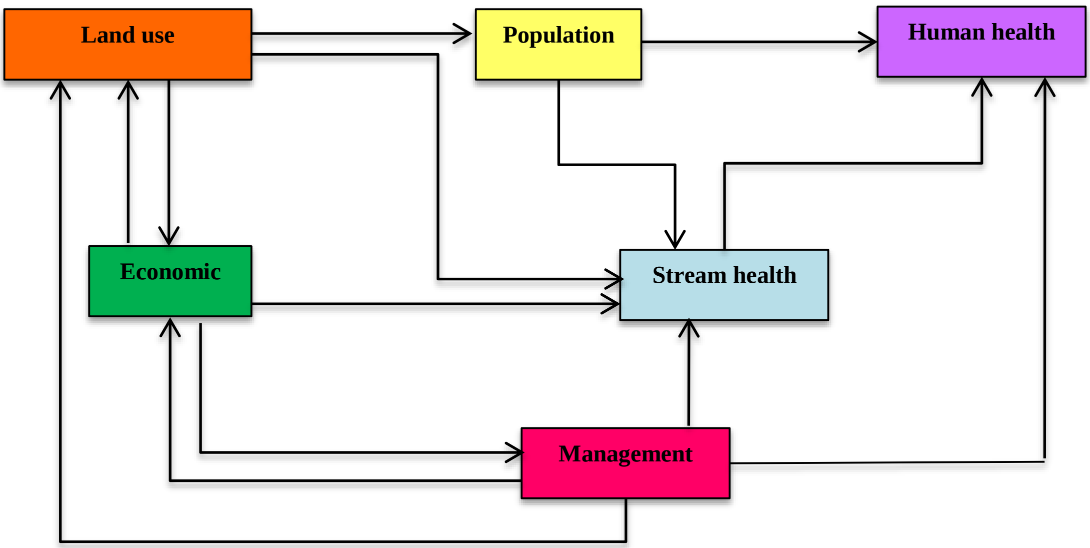


Figure 5-4 Interrelationships between model sectors

The model analysed the influence of DCC interventions in the area looking to coffee farmers' wellbeing, but recognizing the role of other actors involved, thus considering their influence. The model resulted in six sectors, with 17 stocks, 23 flows and 161 converters. 33 people from nine institutions contributed to model development. The following sections describe each model sector, and the understanding achieved as a result of the process.

5.3.1 Population sector

The population sector directly influenced the stream health and human health sectors and was influenced by the land use sector. The population generated impacts on the stream health due to production of domestic wastewater. The population also determined the number of people who were susceptible to diarrhoeal disease.

The population sector structure was built under the assumption that the number of inhabitants in the microcatchment varied as function of births, deaths and net migration (immigration minus emigration). The net migration was influenced by land use. The proportion of area under each land use generated a certain number of jobs according to employment factors associated with each productive activity. The sum of the jobs generated by coffee farming, livestock and commercial forest, versus the working-age population, generated a relationship that had an effect on unsatisfied needs. These unsatisfied needs besides jobs, were health and education. Figure 5-5 includes representation of the factors that through the participatory activities were identified as important to define this model sector. The figure also includes the values of the parameters for the year 2013, for which the quantitative data were collected, and their sources of information.

Table 5-2 provides another summary of information on this model sector.

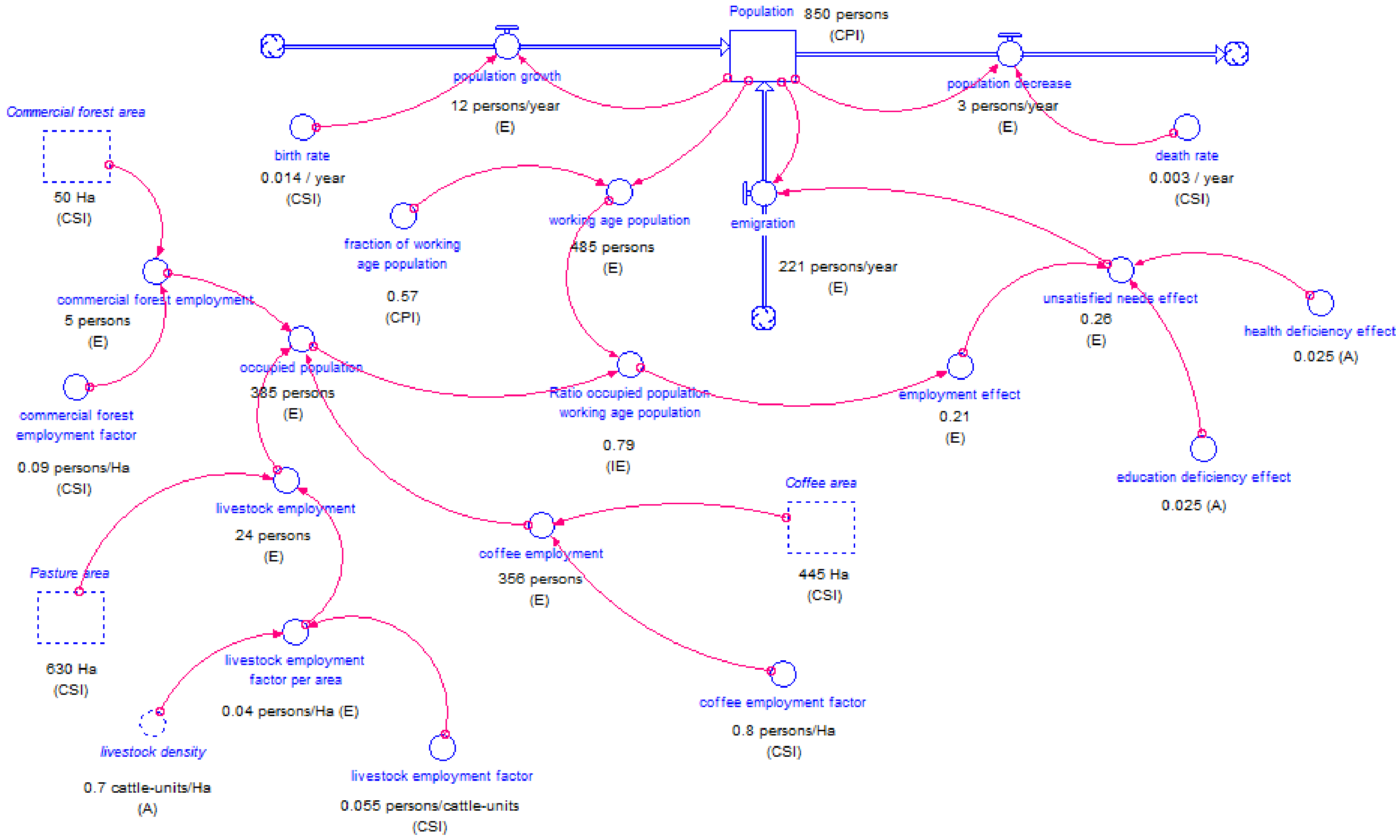


Figure 5-5 Structure of the population sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[13]

[13] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-2 Values for the parameters in the population sector, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Population	S	$persons$	850	CPI
Population growth	F	$\frac{persons}{year}$	12	E
Birth rate[3]	C	$\frac{1}{year}$	0.014	CSI
Population decrease	F	$\frac{persons}{year}$	3	E
Death rate[3]	C	$\frac{1}{year}$	0.003	CSI
Emigration	F	$\frac{persons}{year}$	221	E
Unsatisfied needs effect	C	$dimensionless$	0.26	E
Employment effect	C	$dimensionless$	0.21	E
Health deficiency effect	C	$dimensionless$	0.025	A
Education deficiency effect	C	$dimensionless$	0.025	A
Ratio occupied population working age population	C	$dimensionless$	0.79	E
Working age population	C	$persons$	485	E
Fraction of working age population	C	$dimensionless$	0.57	CPI
Occupied population	C	$persons$	385	E
Coffee employment	C	$persons$	356	E
Coffee employment factor[4]	C	$\frac{persons}{Ha}$	0.8	CSI
Coffee area[5]	S	Ha	445	CSI
Livestock employment	C	$persons$	24	E
Livestock employment factor per area	C	$\frac{persons}{Ha}$	0.04	E
Livestock employment factor[6]	C	$\frac{persons}{cattle-units}$	0.055	CSI
Livestock density	C	$\frac{cattle-units}{Ha}$	0.7	A
Pasture area	S	Ha	630	A
Commercial forest employment	C	$persons$	5	E
Commercial forest employment factor[7]	C	$\frac{persons}{Ha}$	0.09	CSI
Commercial forest area	S	Ha	50	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] PNUD (2008); DANE (2011); (2012); [4] FNC (2013b); [5] CDC (2012); [6] Fedegan (2006); (2012): [7] DNP (2013a).

Some insights emerged from the data in Table 5-2. The important effect of coffee cultivation on rural employment is well known in Colombia. This activity is labour intensive and this is one reason why the sector has contributed to rural development (FNC, 2011; Cano *et al.*, 2012; FNC, 2012; DNP, 2013a). By quantifying the generation of direct employment from the main productive activities in the study area, the social importance of coffee becomes clearer. The coffee industry generates 0.8 jobs/Ha, while commercial forest generates 0.09 jobs/Ha and livestock 0.04 jobs/Ha. In addition, coffee generates seasonal jobs to meet the higher burden of work involved in harvest and postharvest activities (Fonseca, 2003; FNC, 2012).

In *Calabazas*, as in many rural regions in Colombia, coffee growers and ranchers are mostly workers on their own farms. In these farms, most of the activities are undertaken by family labour, creating their own employment (Fonseca, 2003). However, progressive reductions in the size of the plots, makes that all jobs required by family members cannot be provided and leads to migration (Fonseca, 2003; Robledo, 2007). This phenomenon was clear from the results presented in Chapter 4. Besides the lack of employment, migration also occurs because other basic needs cannot be met. As shown in Chapter 4, in the microcatchment people had difficulties to effectively access education and health. The last census conducted in Colombia in 2005, indicated that between 2000 and 2005, 21% of the rural population of Valle del Cauca moved to cities. Among the reasons for emigration were: difficulty getting a job (28%), need for education (5%) and health reasons (5%) (DANE, 2005).

The quantification process found that by 2013, the jobs created in the microcatchment against the working-age population that was not studying was 79%, in consequence 21% of the population lack employment alternatives. This value is slightly lower compared to the value suggested by the 2005 Census (28%). Regarding the effect of migration due to lack of access to health and education, slightly lower proportions of the Census 2005 were adopted, as were considered reasonable for the situation in *Calabazas*.

Migration from the countryside to the cities has been an important phenomenon in Colombia in the last two decades. In particular, migration of women for the relative lack of opportunities for them in the rural areas. Thus, the proportion of men in these places has increased (DNP, 2007). In the coffee zone, due to the coffee crisis since the 1990s, some households are made up of grandparents raising grandchildren in support of those who have emigrated. It has been accepted as normal, that the family institution in this zone has one or more of its members as migrants (Murillo, 2010). This has led to a relative aging of the rural population by reducing the participation of groups less than thirty years (DNP, 2007). According to Narvaez and Velasquez (2009), migration of the younger generation is not only result of the coffee crisis. Also in good times, the children were sent to study in cities and did not return. All these aspects were seen to a greater or lesser extent during the fieldwork in *Calabazas* and were reflected in the behaviour of the indicators discussed in Chapter 4.

The population stock should estimate the number of people in *Calabazas* at a given time. The National Department of Statistics of Colombia (DANE) produces estimates for the rural population of Valle del Cauca. These estimates are shown in Figure 5-6 from the year 1985 to 2013. As there are no specific data for *Calabazas*, but this place is a rural population of Valle del Cauca, the trend from DANE estimates, could be used as the reference mode of behaviour for the population stock in the study area.

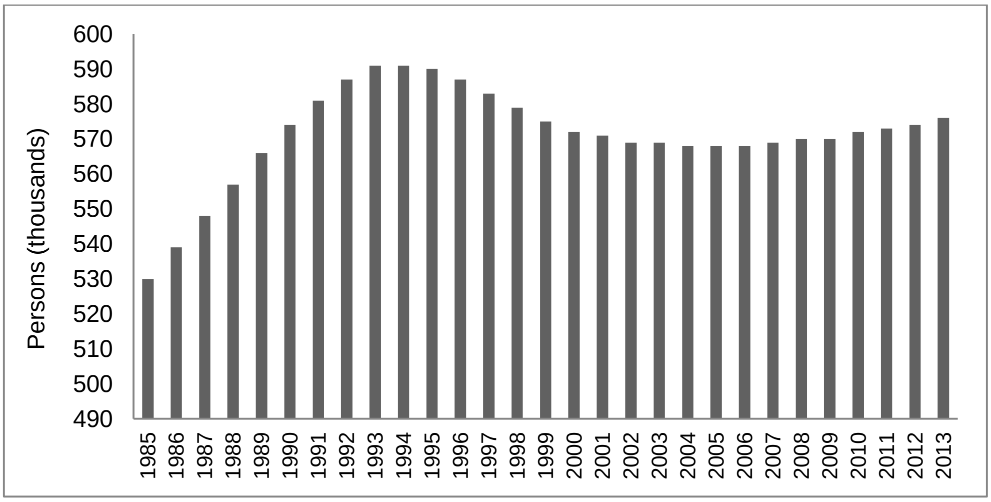


Figure 5-6 Trend of rural population in Valle del Cauca

Own, data source: (DANE, 2011)

Rural population in Valle del Cauca shows a tendency to overshoot and collapse from 1985 to 2006, from when it starts to have a discreet upward trend until 2013. However, from what was observed in *Calabazas*, it would be possible that the pattern of overshot and collapse has continued through 2013. Possible future scenarios could be: i) the structure of land use is maintained, which would make the current levels of migration persist; ii) areas under coffee are converted to pasture or commercial forest, which would deepen migration due to lower employment generation; iii) area under coffee increased, which would generate more jobs and reduce migration, but this would be limited by the availability of land with suitable conditions to growth this crop; iv) new economic activities are promoted (e.g. nature tourism or Payment for Environmental Services - PES), offering diversified livelihoods, reducing migration, although, this will be subject to significant government investments.

5.3.2 Economic sector

The economic sector was focused in the three main productive activities that had place in *Calabazas*: coffee farming, livestock farming and commercial forestry. Each of these activities was divided in a module. Coffee growing was further divided, separating profitability for coffee families from the profitability of the FoNC, given the importance of this last on people wellbeing in the coffee regions. In each of these modules, the stock of interest was the profitability of the respective productive activity. The next sections describe these modules.

Coffee farming

Each family needs to generate sufficient resources to ensure an adequate quality of life. For each coffee grower's family, the profitability of the business depended on the income generated by the sale of coffee minus the production costs. Income depended on crop yield, area planted and the national coffee price. A large number of factors determined crop yield. However, this aspect was itself so complex that the group agreed that most relevant factors were crop density and the plantation age. The variety planted, also an important aspect, was not included since in *Calabazas* most of the coffee plantations were under the *Castillo* variety, resistant to rust. Renovation of plantations with this variety was possible after a national program from which this microcatchment was beneficiary.

Domestic coffee price depended on the international Colombian coffee price in the New York Stock Exchange and the exchange rate of the Colombian Peso (COP) against the U.S. Dollar (USD). During 2013, due to the poor performance of these two factors, a price subsidy was granted because the majority of coffee farmers were insolvent. Therefore, this subsidy also influenced income. This subsidy was given subject to the domestic price was below a ceiling value agreed through negotiations between the coffee growers and the government.

Production costs depended on the type of coffee producer (large, medium, small), the region of the country, and the variety planted, among other factors. Due to the type of coffee that was grown in Colombia and the topography of the coffee zone, labour was approximately 70% of the costs, and this proportion is unlikely to be changed. DCC had a program in which in each microcatchment, coffee farmers met periodically with their extension worker to determine production costs in each jurisdiction, and identify changes that could be made to increase profitability. These costs were used to generate statistics and action plans at the department level. Thus, production cost factors based on the quantity of coffee produced for *Calabazas* were available.

Figure 5-7 shows the module within the economic sector regarding coffee farmers' profitability, including the factors that comprise structure, their numerical values for 2013, and their information sources. Table 5-3 provides another summary of the relevant information for this model sector.

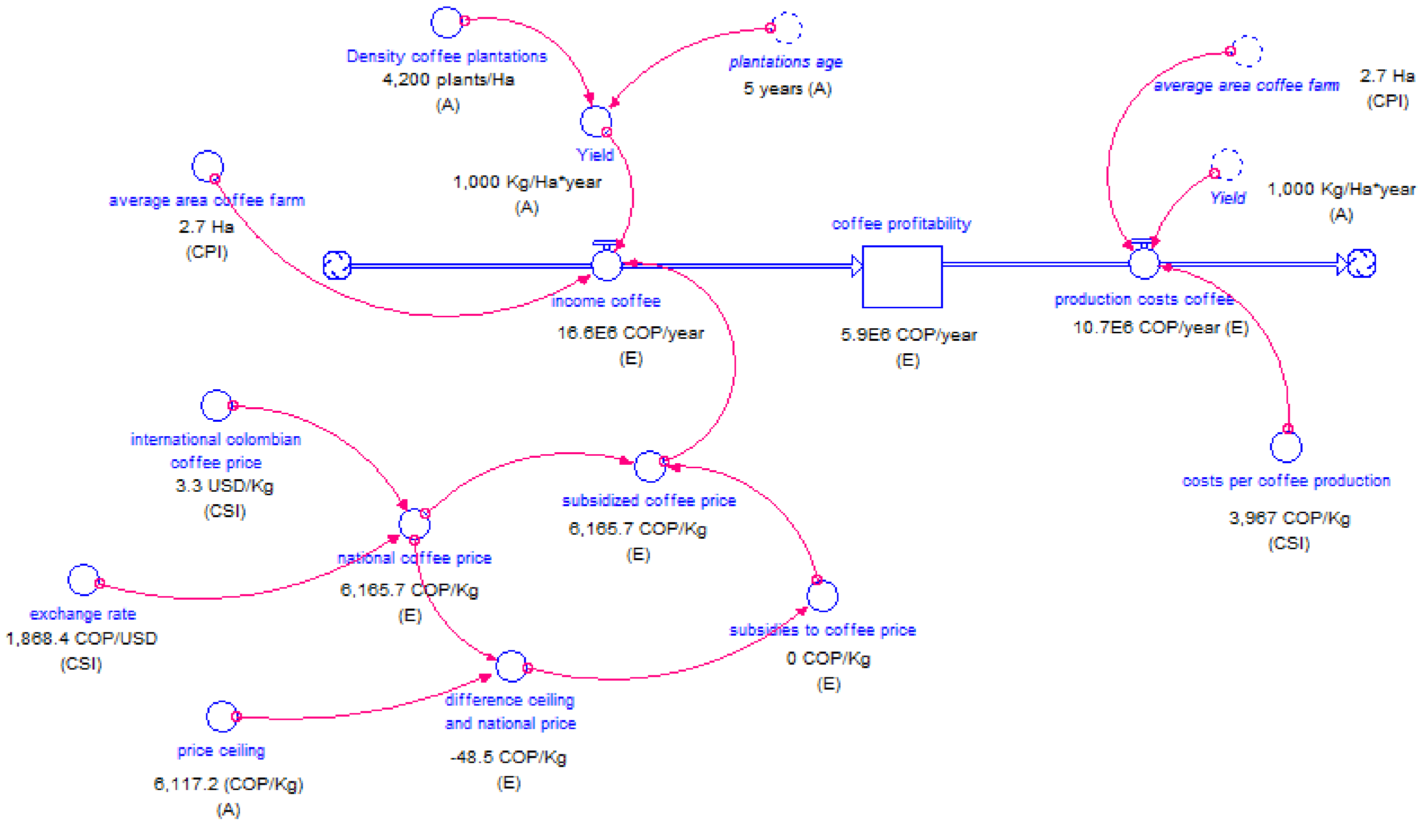


Figure 5-7 Structure of the coffee farming module from the economic sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[14]

[14] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-3 Values for the parameters in the economic sector – coffee farming, year 2013[15]

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Coffee profitability	S	$\frac{COP}{year}$	5.9E6	E
Income coffee	F	$\frac{COP}{year}$	16.6E6	E
Average coffee farm	C	Ha	2.7	CPI
Yield	C	$\frac{Kg}{Ha * year}$	1,000	A
Density coffee plantations	C	$\frac{plants}{Ha}$	4,200	A
Coffee plantations age	C	years	5	A
Subsidized price	C	$\frac{COP}{Kg}$	6,165.7	E
Subsidies to coffee price	C	$\frac{COP}{Kg}$	0.0	E
Difference ceiling and national price	C	$\frac{COP}{Kg}$	-48.5	E
National coffee price[3]	C	$\frac{COP}{Kg}$	6,165.7	E
Price ceiling	C	$\frac{COP}{Kg}$	6,117.2	A
Exchange rate[4]	C	$\frac{COP}{USD}$	1,868.4	CSI
International coffee price[3]	C	$\frac{USD}{Kg}$	3.3	CSI
Production costs coffee	F	$\frac{COP}{year}$	10.7E6	E
Costs per coffee production[5]	C	$\frac{COP}{Kg}$	3,967	CSI

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] FNC (2014); [4] Superfinanciera (2013); [5] FNC (2013a)

The critical factors for the income of coffee families were: price, farm size and productivity. Price was subject to fluctuations over which control was challenging in a free market environment. The international price depended on production in other countries, and speculation with grain on international markets. The exchange rate in

15 Profitability in a typical coffee farm in the microcatchment

Colombia was set by a central bank to control inflation and since 2004, the trend has been revaluation, which generated via this single factor, substantial losses for the coffee industry. This situation bottomed out in 2013 when unprecedented agricultural strikes in Colombia occurred. At the time of writing, due to a political juncture, there was a significant peso devaluation. However, it was possible that this devaluation was ephemeral, since the policy in the last 20 years, was favouring foreign investment, for which revaluation was needed and no devaluation, which was what benefits coffee growers. Subsidies were a temporary alternative to alleviate the crisis, but subsidized coffee farming was widely considered unsustainable, despite the social impact of coffee farming in Colombia, where 560,000 families directly depended on this activity.

Cano *et al.* (2012) indicate that given the cost structure in coffee production (70% is labour), and the large number of families involved, if the income of the workers hired by coffee farms increased 10%, it would generate an increase in Gross Domestic Product (GDP) equivalent to 43 points. In contrast, if this adjustment was applied to the income of oil workers, the domestic product would increase only four basic points. With these figures, the authors emphasize the importance of coffee for poverty reduction and income distribution in the rural population.

In relation to farm size, coffee farms were subdivided through generations arriving at the microfundio, where most of the farmers had less than 5 hectares. In *Calabazas*, coffee plots averaged 2.7 Ha. García and Ramírez (2002) concluded that coffee farms with less than 5 Ha are not able to generate sufficient income to ensure the satisfaction of the basic needs of a family. However, participants in the modelling process believed that due to the use of family labour, it was still possible to make a living from these small farms.

The plantations yield was another important factor on profitability. This factor was related to the possibilities of farmers to invest in their lands and to the interventions of the NFC, addressed in the management sector of the model. As explained before, during modelling, it was decided that productivity depended mainly on density and plantation age. In terms of density, according to DCC staff, climatic and soil conditions in *Calabazas* did not allow densities greater than 5,000 plants per hectare, and most farms had plantations with densities about this level. Regarding age, the coffee plant is perennial, requires 1.5 to 2.0 years for the first harvest and reaches its maximum growth and productivity between years 6 and 8 (Finagro, 2013b). After this age, productivity decreases and consequently profit. In general, it is recommended to divide a farm into several plots, and each year one plot is renovated to maintain a reasonable average yield, year after year. As explained earlier, in the last years *Calabazas* benefited from renovation programs.

Concerning production costs, work by DCC with farmers included the costs of all production factors, and these were incorporated in the model with the understanding that farmers labour ought to be monetized. However, since in these small farms most of the work was developed by family members, the cash that farmers provided to cover production costs was approximately 60% - 70% lower than that used by the model, therefore, they could perceive that profitability was higher. For this reason, it was believed that the crisis was stronger for large farmers who had to pay for all production factors, compared with small farmers contributing substantially to labour costs.

Figure 5-8 presents the available historical trends for some of the factors that influence profitability for coffee farmers. Figure 5-8 (a) shows the international coffee price, Figure 5-8 (b) shows exchange rate, Figure 5-8 (c) the national price, and Figure 5-8 (d) yield.

Before the 1990s, the domestic coffee price was influenced by a market intervention, the Pact of Odds. With free trade, this pact was broken and since then, the price was heavily influenced by the international price and the exchange rate (DNP, 2013b). International prices below the mean of the series occurred between 1990 – 1993 and 1999 – 2006. On the other hand, coffee being a product intended mainly for export, revaluation reduced the competitiveness of exports. Under revaluation, the revenue generated by the international price loss considerable value when converted to a currency revaluated against the dollar. The year 2013 was dramatic for coffee farmers due to the combined effect of low international prices and high revaluation.

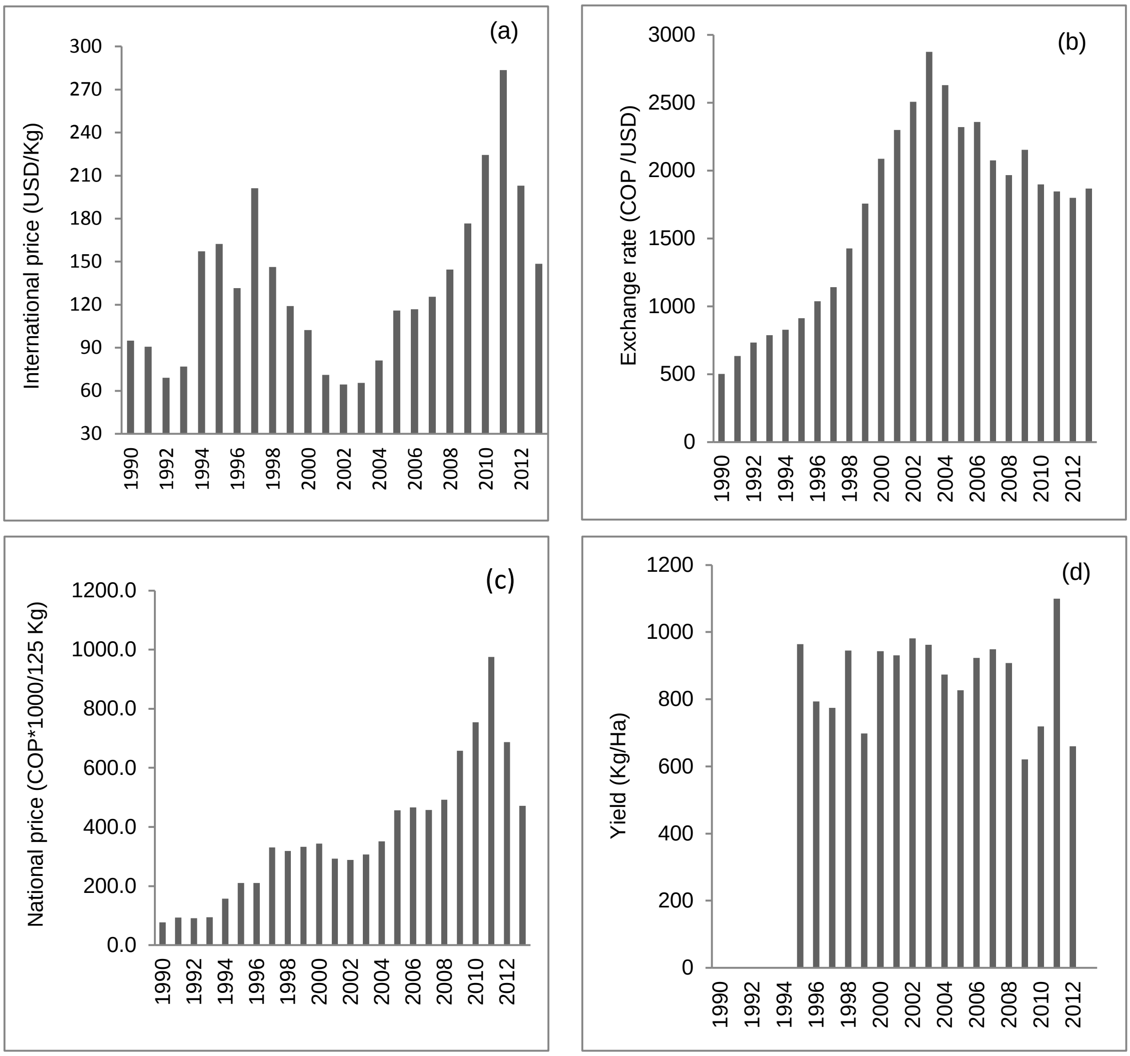


Figure 5-8 Trends of some of the factors affecting coffee production profitability (a) international coffee price; (b) exchange rate; (c) national coffee price; (d) yield.

Own, data source: FNC (2014)

Resources to the National Coffee Fund

The FoNC was a para-fiscal fund with resources of public nature. Colombian coffee farmers, unionized through the NFC, contributed to this fund and the resources were used to provide a range of services which included: purchase warrant, marketing, rural extension, research, quality control, commercialization, and social investments (FNC, 2011). Investments undertaken by DCC in microcatchments of Valle del Cauca are made with resources from this fund. This module of the economic sector represents the resources collected by the FoNC. The income from the FoNC depended on the Coffee Contribution (CC) and other sources of funding. The CC depended on the amount of exported coffee, the exchange rate and a factor agreed by the guild. Figure 5-9 shows the FoNC module within the economic sector.

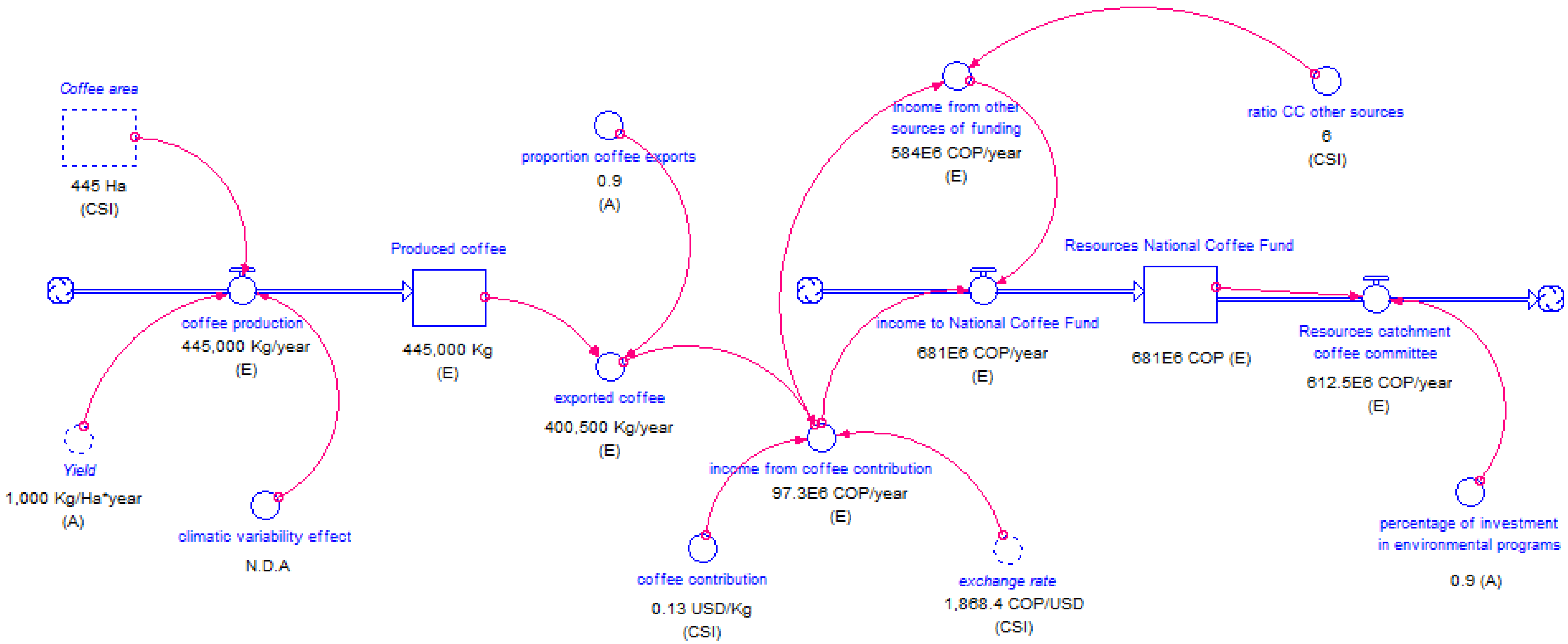


Figure 5-9 Structure of the resources to the FoNC module from the economic sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[16]

[16] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-4 summarizes relevant information about this module, including factors that made the structure, their numerical values for 2013, and their information sources.

Table 5-4 Values for the parameters in the economic sector – resources to the FoNC, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Resources to National Coffee Fund	S	COP	681E6	E
Percentage of investment in Environmental Programs	C	dimensionless	0.9	A
Resources catchment Coffee Committee	F	$\frac{COP}{year}$	612.5E6	E
Income to National Coffee Fund	F	$\frac{COP}{year}$	681E6	E
Income from other sources of funding	C	$\frac{COP}{year}$	584E6	E
Ratio CC other sources[3]	C	dimensionless	6	CSI
Income from coffee contribution	C	$\frac{COP}{year}$	97.3E6	E
Exchange rate[4]	C	$\frac{COP}{USD}$	1,868.4	CSI
Coffee contribution[5]	C	$\frac{USD}{Kg}$	0.13	CSI
Exported coffee	C	$\frac{Kg}{year}$	400,500	E
Proportion coffee exports	C	dimensionless	0.9	A
Produced coffee	S	Kg	445,000	E
Coffee production	F	$\frac{Kg}{year}$	445,000	E
Climatic variability effect	C	dimensionless	No data available	No data available
Coffee area[6]	S	Ha	445	CSI
Yield	C	$\frac{Kg}{Ha * year}$	1,000	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] FNC (2011); [4] Superfinanciera (2013); [5] FNC (2014); [6] Cafeteros-Valle (2012).

The CC was 0.13 COP per kg of green coffee exported. This value was set from 2006, after NFC reduced about 80% its assets and undertook an austerity program in the preceding years. Between 2006 and 2009, the CC was the main source of income to the FoNC, given the average historical levels of coffee production, and exchange rate projections at that time. However, since 2009, revenues from CC decreased dramatically and other sources of income were necessary to ensure continuity of programs (DNP, 2013a). These alternative sources were funds from national, departmental and local governments, and from international cooperation. Thus, on average, between 2006 and 2011, FoNC showed a leverage ratio of resources of 6.1, i.e. for one COP from the CC, other funding sources provided 6.1 COP (FNC, 2011).

The CC for *Calabazas* depended on the coffee production and the proportion of this production for the external markets. The production corresponded to the area under coffee at the microcatchment scale, and the average yield of coffee plantations in the region. Production was also affected by a reduction factor due to climatic phenomena. The way climate affects production was complex. During El Niño, coffee berry borer increases. During La Niña, excess rain, low temperature and sunshine are unfavourable conditions for coffee flowering, and also encourage coffee rust (Cenicafé, 2011). Both the decrease of flowering and the pests decrease production. However, neither the modeller group, nor the interviewees attempted to assign a value to this factor of reduction in productivity due to climate variability.

The resources generated as CC from a microcatchment were not directly the resources available for investment. Likewise, not all funds generated were invested in programs aimed at environmental health and human health and wellbeing. The group could not agree on a factor of investment for environmental programs in the microcatchment. Based on the behaviour in *Calabazas* during 2013, the factor for that year was 0.9. However, the factor used by the NFC nationwide is 0.06 (FNC, 2012). The high factor for *Calabazas* in 2013 was primarily due to the resources of PFP, and to the fact that investments in coffee plantations renovation were considered one of the strategies to improve human and catchment health. Figure 5-10 presents the available historical trends for some of the factors that influenced resources to the FoNC: Figure 5-10 (a) coffee production and Figure 5-10 (b) coffee contribution.

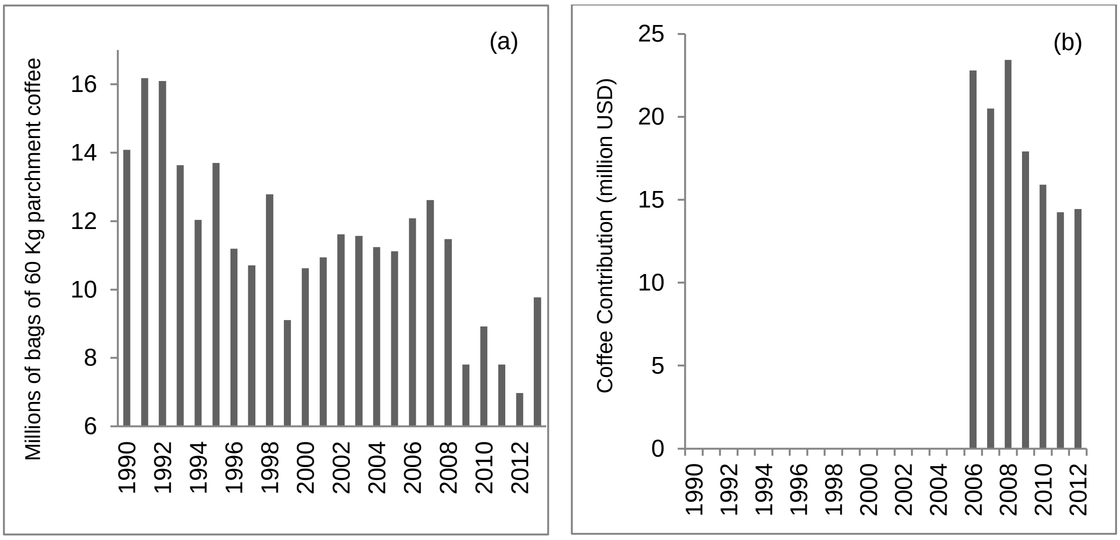


Figure 5-10 Trends of some of the factors affecting resources to the FoNC
(a) coffee production; (b) coffee contribution

Own, data source FNC (2014)

Between 2008 and 2013, Colombia had the lowest coffee production in the period 1990 - 2013. These low production levels were caused by extreme climatic phenomena, and by having large areas out of production for poor planning on the renovation strategy. The low production coincided with the appreciation of the peso. Therefore, income from CC to the FoNC also showed low levels during this period.

Livestock farming

The livestock module was also articulated about profitability. In *Calabazas*, the modality of livestock was Dual Purpose (DP). DP is a production system, practiced in Latin America, in which local cattle are crossed with European breeds and used to produce milk and meat using local and low cost inputs (Ortega and Ward, 2005). Thus, the income is derived from the sale of milk and meat. Income from each of these products depended on the quantity produced and their market price. The production costs of milk depended on the quantity produced and a factor of production per volume. Likewise, the costs of meat production were a function of the produced meat and the associated production costs. The profitability of DP livestock farming was determined by the difference between income and production costs. Figure 5-11 shows the livestock profitability module in the economic sector, including the factors that made the structure, with their numerical values for 2013 and codes indicating their information sources.

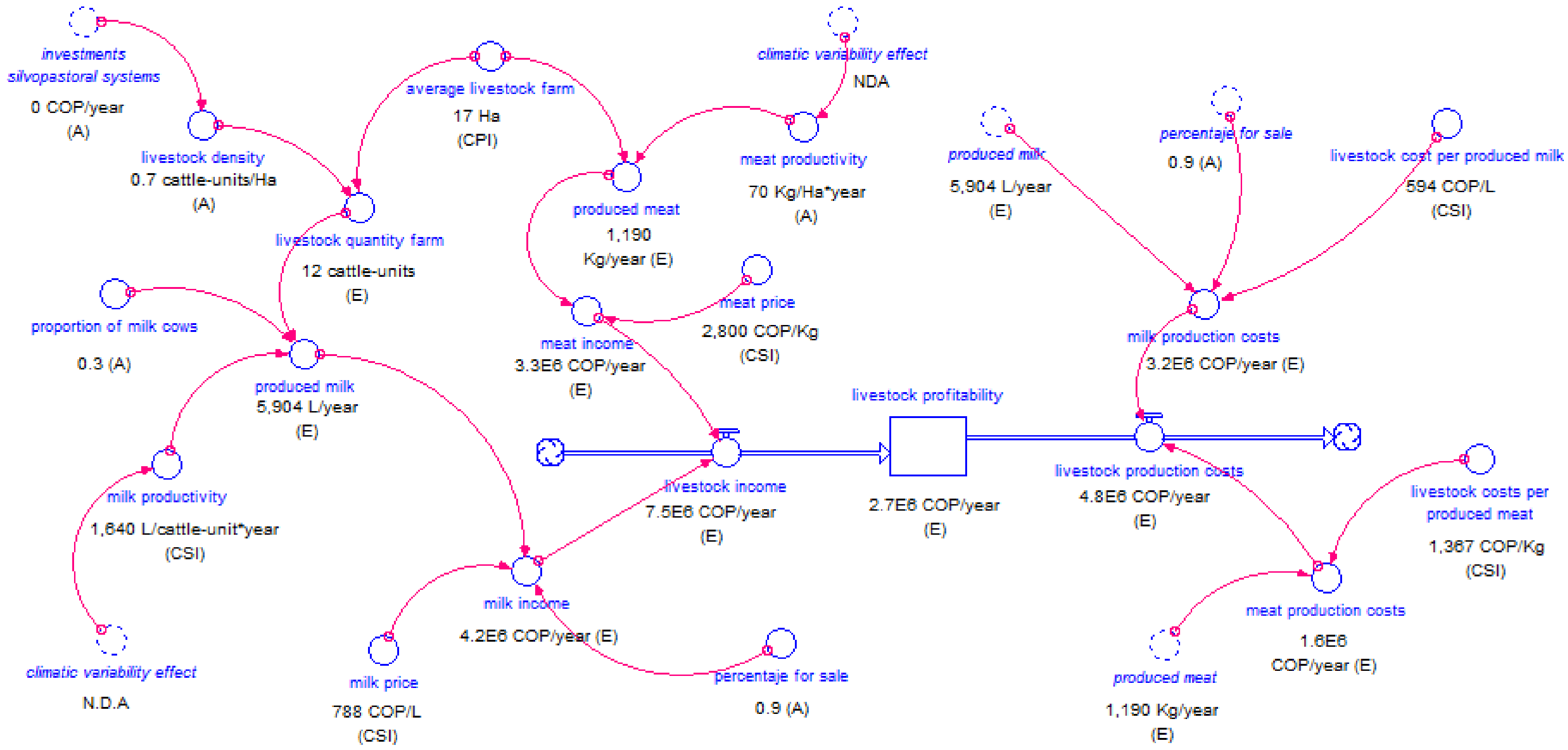


Figure 5-11 Structure of the livestock farming module from the economic sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[17]

[17] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

The herd size influenced the quantity of milk produced. It depended on the number of animals per hectare, and the average area of the livestock farm. In *Calabazas*, the average cattle farm was 17 Ha, larger compared to the coffee farms, and closer to urban centres. However, this area along with the density (0.7 animals per hectare) gave only a number of 12 animals per farm. Over 80% of livestock farmers in Colombia, own less than 50 animals, and livestock at this scale does not provide enough income for a family (Fedegan, 2006; 2013c).

For the model, the herd included dairy cows, calves and dry cows. Income from milk depended on the proportion of dairy cows, their average productivity, the proportion of produced milk allocated for sale, and the milk price. According to the stakeholders from the livestock sector, small livestock farms had poor productivity. The birth rate was low, whereby the milking cows were estimated only on around 30% of the herd. Milk production reached 1640 L/cow*year. Furthermore, rangelands in *Calabazas* were degraded, with native pastures, where no fertilization or pasture management were carried out. Therefore, animals did not have good food and farmers lacked resources to supplement the diet.

Income from meat depended on acreage, and meat productivity. The average meat productivity in Colombia is 110 Kg/ha*year (Ganadero, 2013a). Given *Calabazas* conditions, a productivity of 70 Kg/ha*year was assumed. It implicitly considered a low extraction rate, and the possibility that animals used for meat, reached weights only of about 120 kg, and were sold to be fattened by larger farmers.

Climate variability also affects milk and meat production. El Niño reduces the availability of forage and water for animal consumption, and causes heat and water stress. During the El Niño is likely that density of livestock needs to be reduced (Fedegan, 2010). La Niña causes flooding, but this did not create major problems in this area, since the land was hilly.

In Colombia, it is estimated that labour represents about 56% of production costs in DP farms (Fedegan, 2010). Other costs are grassland maintenance, food, supplements and health. The model used total production costs based on reports from the livestock sector (Fedesarrollo and Iquartil, 2012; Ganadero, 2013a). These costs include labour and were checked with Cogancevalle[18] to determine whether they were reasonable for *Calabazas*. As in the case of coffee, since an important proportion of the cost is labour, and that labour was from family members, perceived profitability could be higher than estimated. Table 5-5 provides another summary with information about this module.

Table 5-5 Values for the parameters in the economic sector – livestock farming, year 2013[19]

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Livestock profitability	S	COP	2.7E6	E
Livestock income	F	$\frac{COP}{year}$	7.5E6	E
Milk income	C	$\frac{COP}{year}$	4.2E6	E
Percentage for sale	C	dimensionless	0.9	A
Milk price[3]	C	$\frac{COP}{l}$	788	CSI
Produced milk	C	$\frac{l}{year}$	5,904	E
Milk productivity[4]	C	$\frac{l}{cattle-unit*year}$	1,640	CSI
Climatic variability effect	C	dimensionless	No data available	NDA
Proportion of milk cows	C	dimensionless	0.3	A
Livestock quantity farm	C	cattle-units	12	E
Average livestock farm	C	Ha	17	CPI
Livestock density	C	$\frac{cattle-units}{Ha}$	0.7	A
Meat income	C	$\frac{COP}{year}$	3.3E6	E
Produced meat	C	$\frac{Kg}{year}$	1,190	E
Meat productivity[4]	C	$\frac{Kg}{Ha*year}$	70	A
Meat price[3]	C	$\frac{COP}{Kg}$	2,800	CSI
Livestock production costs	F	$\frac{COP}{year}$	4.8E6	E
Milk production costs	C	$\frac{COP}{year}$	3.2E6	E

18 Cogancevalle is the Cooperative of livestock farmers, sectional of the Colombian Federation of Livestock farmers (Fedegan) for the centre and north of Valle del Cauca department, located in *Tuluá*
19 Data for a typical livestock farm in the microcatchment

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Livestock costs per produced milk[5]	C	$\frac{COP}{L}$	594	CSI
Livestock costs per produced meat[5]	C	$\frac{COP}{Kg}$	1,367	CSI
Meat production costs	C	$\frac{COP}{year}$	1.6E6	E

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] Fedegan (2013a); [4] Fedegan (2006); (2011); [5] Fedesarrollo and Iquartil (2012) and Ganadero (2013b).

Figure 5-12 presents the available historical trends for some of the factors that influenced profitability for livestock farms. Figure 5-12 (a) shows national milk production; Figure 5-12 (b) presents national meat production; Figure 5-12 (c) includes average national milk price; and Figure 5-12 (d) shows the average national meat price.

As shown in Figure 5-12 (a), milk production increased substantially between 2000 and 2011, with peaks in 2002 and 2008. It is estimated that between 1990 and 2009, production grew at a rate around 3%, higher than the population growth rate and much higher than the average milk per capita consumption rate .This situation arose because many producers of other agricultural products affected by the economic liberalization of the 1990s sought their livelihoods in milk production (Suarez, 2010).

Figure 5-12 (b) shows meat production evolution. Between 2000 and 2012, it increased steadily but slower than milk, at a rate of 2.4% per year. In the country, 90% of the beef produced is consumed (Ganadero, 2013b).

Figure 5-12 (c) contains a short time series of average milk prices, showing a significant increase from 2011 to 2013, probably associated to climate change and drought in New Zealand in this period. Despite recent high prices, based on the information obtained from different sources, milk producers were in a critical situation. Five large processing companies acquired approximately 60% of the production and the remainder was sold through informal channels or small cooperatives (Fedegan, 2013b). These large companies controlled the price; the primary producer was highly vulnerable to this situation. This was compounded by various factors: i) the signing of several free trade agreements with economies where the dairy industry was more productive and highly subsidized compared to Colombia; ii) the weak customs controls that allowed entrance of larger amounts of product than agreed, and iii) the seasonality in production, which increased in rainy season. Large companies preferred buying the cheaper milk from international markets, rather than buying from local producers. In rainy season, although the local milk reduced its price due to greater productivity, the price to the final consumer, controlled by these companies, did not decrease, and lower prices were not translated into higher consumption. All these situations made, production costs higher than the sale price, causing losses to small local producers (Suarez, 2010; Fedegan, 2013b; 2013c).

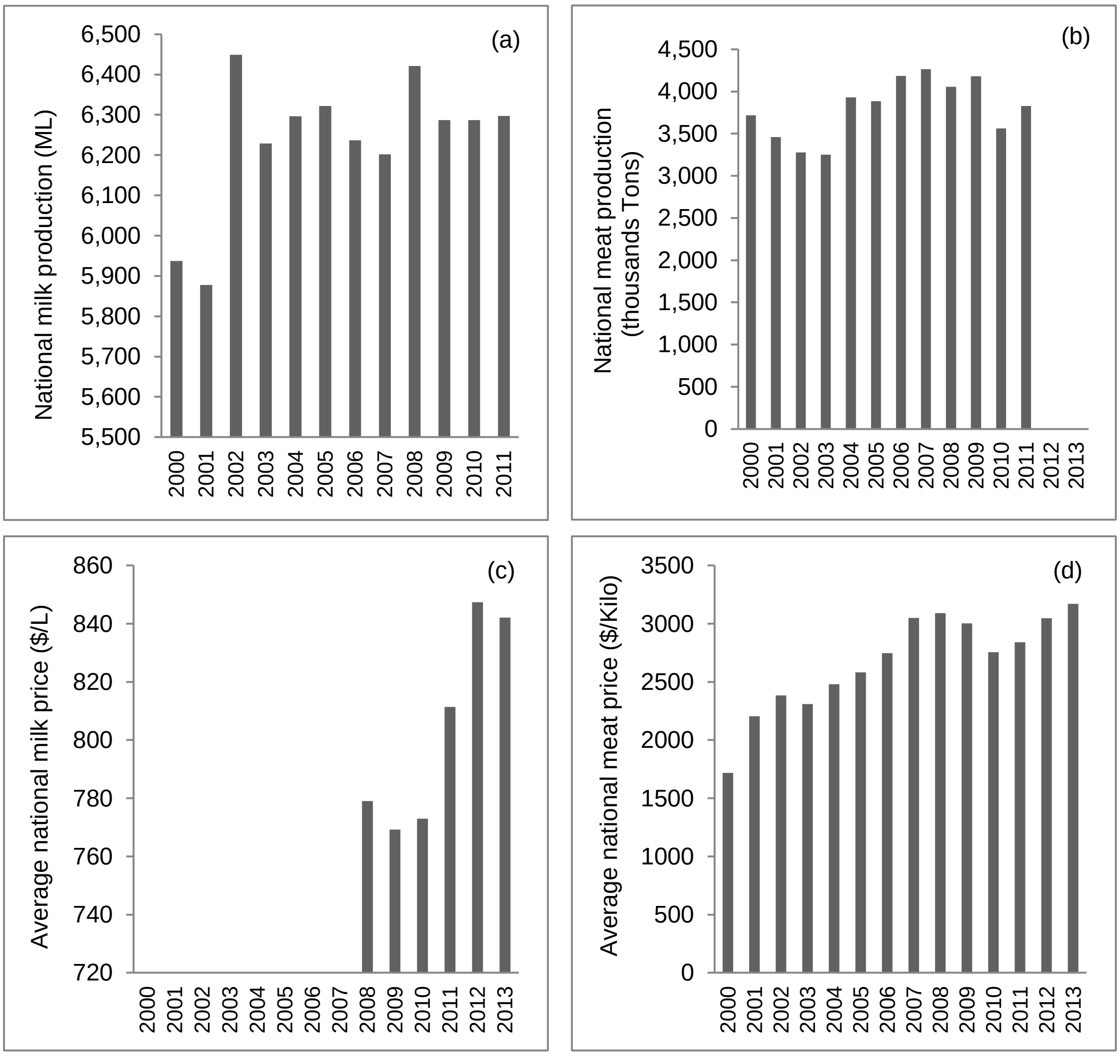


Figure 5-12 Trends of some of the factors affecting livestock profitability (a) national milk production; (b) national meat production; (c) average national milk prince; (d) average national meat price.

Own, data source: (Fedegan, 2013a)

Meat prices performed better with a steady increase between 1999 and 2013, with peaks from 2006 to 2008, and lowest prices from 2010 to 2011 (Figure 5-12 – d). Meat prices were generally above production costs and local demand was high (Ganadero, 2013b). The domestic beef prices remained lower than those of the imported meat, and the country was still not a target market for major global producers, favouring local farmers.

In general, in Colombia livestock profitability was a cyclical phenomenon, responding to international prices, free trade, the dominant position of milk processors, seasonality, climatic variability, and consumption habits of customers, among others. Since 2006, all the inputs used in livestock were above the Consumer Price Index, while its products, especially milk were below this index. This decreased the purchasing power and savings opportunities, capitalization and growth for farmers (Fedegan, 2006; 2010; 2011). Furthermore, livestock institutionalism was not developed to the level of that from coffee farmers. The coverage of extension, credit, and training was low, and usually did not reach small livestock keepers. Ranchers had to pay a fee to become members of Fedegan, the National Federation of livestock farmers. That fee was an entry barrier for small ranchers. For example, the membership level in Valle del Cauca was less than 10% of livestock keepers. In *Calabazas*, there were no members; therefore, livestock farmers in this area did not have access to technical assistance. In addition, livestock farmers´ culture was not keen on association; there was individualism, and mistrust to share information. All these factors prevented business´ improvements being made.

Commercial forestry

Forestry in *Calabazas* occupied a small area (50 Ha), and was developed by a multinational company. However, a module was developed for this productive activity. The profitability of commercial forest plantations was given by the income from sales and the production costs. Income depended on productivity, price and subsidies. Productivity was the timber volume per hectare obtained per year. The price was the market price of timber, in this case, pulp used for paper production. Additionally, in Colombia, this activity was subsidized. Owners of forest plantations received an established amount of money per planted hectare for establishment and maintenance. In the model, production costs were given by a cost factor per planted area and the planted area itself. Figure 5-13 shows the commercial forest module in the economic sector, showing factors, and numerical values for year 2013 with their information sources.

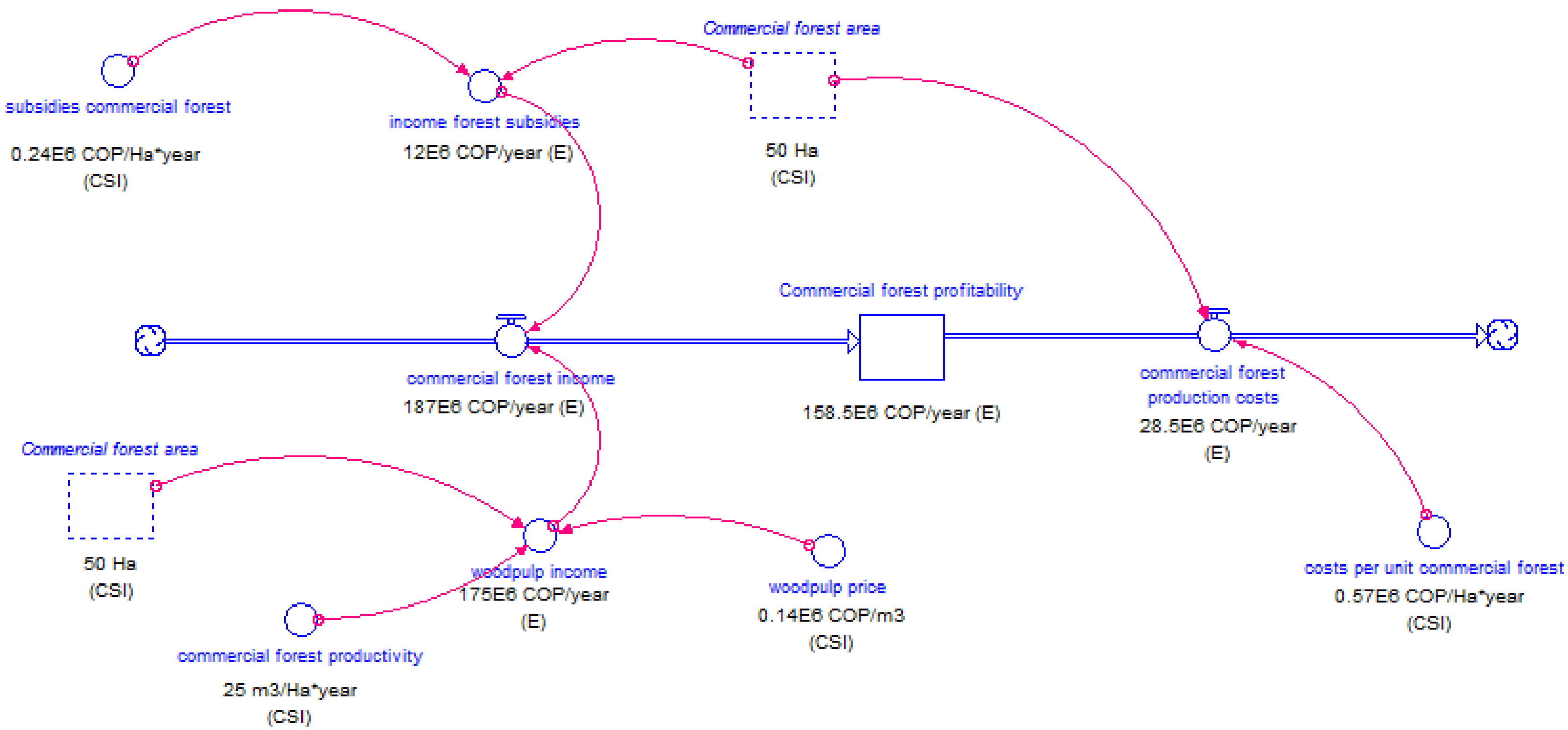


Figure 5-13 Structure of the commercial forestry module from the economic sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[20]

[20] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Promotion of forest plantations has been an ongoing effort of Colombian governments (IDEAM, 2002). It is thought, the country has several advantages for developing this activity: i) proximity to major consumption centres of forest products; ii) 17 million hectares suitable for reforestation; iii) aptitudes for a variety of commercial species; and iv) photosynthesis throughout the year, favouring higher yields and shorter production cycles (MADR, 2011).

The paper pulp production in Colombia has been stable for several years, especially *Pinus patula* and *Eucalyptus grandis* (IDEAM, 2010b). Eucalyptus, the specie grown in *Calabazas*, can achieve yields of up to 30 m^3 /ha /year, with a shift between 7 and 8 years (MADR, 2009).

Updated data on the prices of pulpwood in Colombia were not found. For 2007, prices for round wood placed at pulp mills ranged from 100,000 COP/m^3 to 110,000 COP/m^3 (USAID, 2008). Taking into account the inflation of the period, 4.6% (BanRep, 2014), the estimated value for 2013 would be around 144,155 COP/m^3. With regards to production costs, estimated costs of establishment for 2013 were 1,913,899 COP/Ha, and maintenance costs between 200,000 and 400,000 COP/Ha, depending on plantation age (MADR, 2013).

The Colombian government considered the forestry sector strategic for the country. Commercial reforestation was understood as a productive long-term activity that requires incentives to encourage investment. It was expected that this sector strengths the country's economy with foreign capital and taxes. To promote this activity, since 2000, several incentives were created, including the Forestry Incentive Certificate (CIF) (MADR, 2011). The CIF paid to commercial forest producers 50% of the costs for the establishment of introduced species and 50% of the costs for the maintenance of the plantations (MADR, 2013).

Table 5-6 summarizes information about this module.

Table 5-6 Values for the parameters in the economic sector – commercial forestry, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Commercial forest profitability	S	COP	158.5E6	E
Commercial forest income	F	$\frac{COP}{year}$	187E6	E
Wood pulp income	C	$\frac{COP}{year}$	175E6	E
Wood pulp price	C	$\frac{COP}{m^3}$	0.14E6	CSI
Commercial forest productivity[3]	C	$\frac{m^3}{Ha * year}$	25	CSI
Income from subsidies	C	$\frac{COP}{year}$	12E6	E
Subsidies commercial forest[4]	C	$\frac{COP}{Ha * year}$	0.24E6	CSI
Commercial forest production costs[4]	F	$\frac{COP}{year}$	28.5E6	E
Costs per unit commercial forest	C	$\frac{COP}{Ha * year}$	0.57E6	CSI
Commercial forest area	S	Ha	50	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] USAID (2008); MADR and CONIF (2009); [4] MADR (2013)

No time series on the productivity, price or profitability for this sector were available. No stakeholder took part in the modelling process representing this sector. However, results in Table 5-6 for the year 2013, suggests, in its 50 hectares plantation, the forestry company made a profit higher than a coffee farmer on a 2.7 Ha-plot or a livestock keeper on a 17 Ha-farm. Reasons for this were the amount of planted area and the government subsidies.

For many years, in Colombia, there has been controversy around the performance of the forestry company. Broderick (1998) and Sinaltrainal (n.d.) make several criticisms, including: i) exercise political power that has allowed access to credits, tax benefits, and subsidies (e.g. CIF); ii) achieve that in the Law, introduced species such as Pine and Eucalyptus, are considered autochthonous; iii) transform the Andean or sub-Andean forests to logging areas; iv) eliminate traditional livelihoods in the Andean region; v) control headwaters leading to loss of water sources, reduction or disappearance of flows: vi) fail to fulfil promises of job creation and generation of resources for the country due to tax exemptions and allocation of subsidies for the activity.

5.3.3 Land use sector

The land use sector considered the total area of the microcatchment, the main existing uses, transformations of these, and the factors influencing these transformations. On one hand, the profitability of the activities associated with each use, or incentives to adopt a particular use, and on the other hand, restrictions on the maximum areas for each use, determined by the Environmental Authority for Valle del Cauca Department (CVC) or the biophysical conditions in the area.

Stakeholders corroborated the main uses previously identified in the land use map (CVC, 2012): coffee, livestock, commercial forest and natural forest. During the focus groups, subcategories within these uses emerged. For example, free exposure coffee and shade-grown coffee. In shade-grown coffee, annual productivity is lower, but it is considered more desirable from the environmental perspective. After discussing the issue, it was agreed that systems with shade could be a managerial strategy, although this was contrary to the goal of increasing business profitability. In terms of livestock, the subcategory of silvopastoral systems emerged. It was also agreed that they would be a managerial strategy. Contrary to the case of shade-grown coffee, silvopastoral systems improved both productivity and environmental performance.

The total microcatchment area was conserved and divided in the four stocks with the categories previously mentioned. There were transformations between each land use and the total microcatchment area. The transformations were given by the demands of land for each use, depending on the profitability of the activity, and incentives such as subsidies or government programs for a particular sector. The possibility to expand a land use was determined by the maximum area that such use could occupy. CVC defined this maximum area for each of the catchments in Valle del Cauca on maps of potential land use. However, they generally lacked effective mechanisms to enforce these restrictions.

Figure 5-14 includes representation of the factors identified as important to define the land use sector, and their values for 2013, with their information sources.

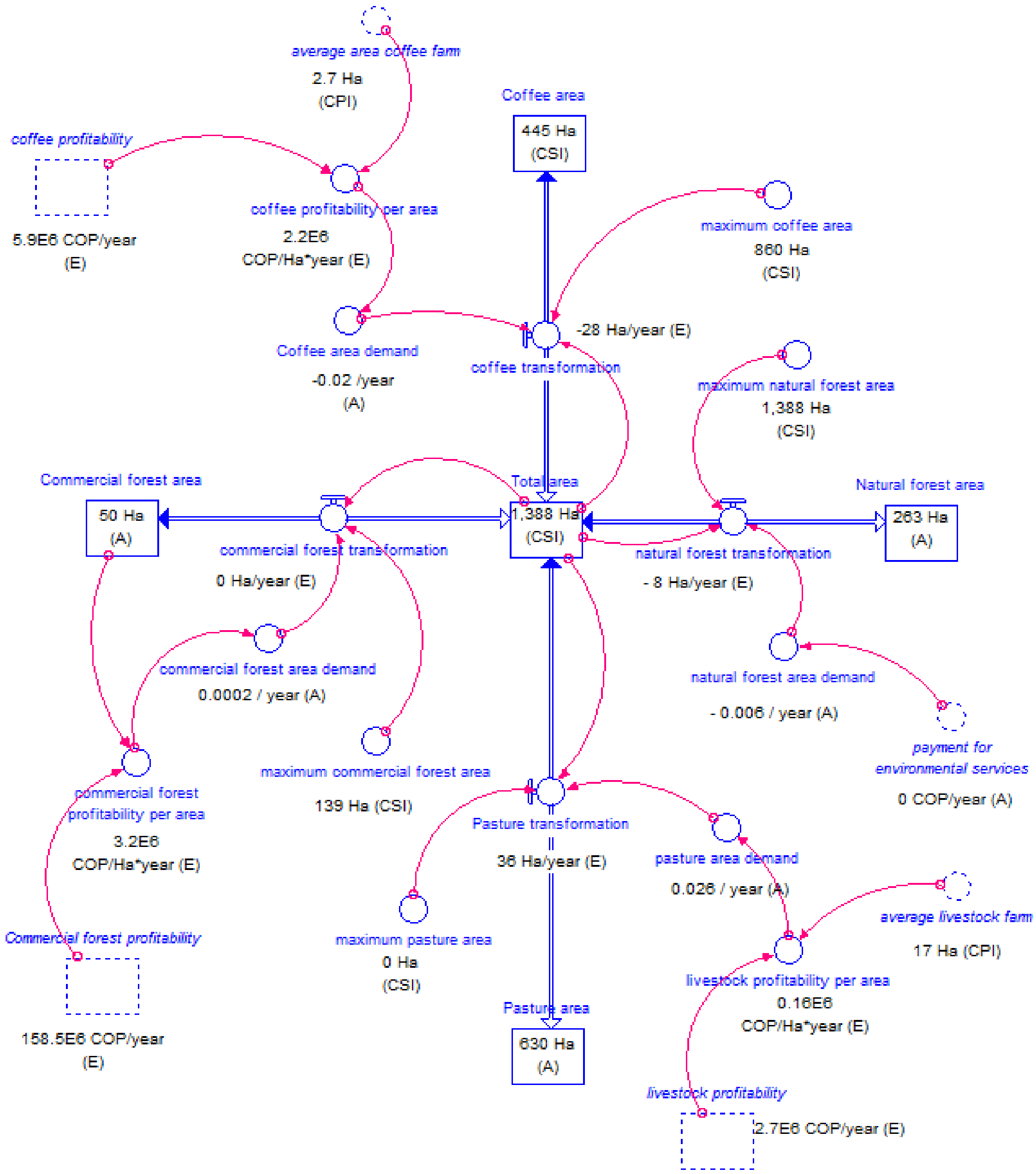


Figure 5-14 Structure of the land use sector produced using the Stella software, values of the parameters for the year 2013, and sources of information [21]

The total area of *Calabazas* was 1,388 Ha. The land use map indicated that 877 Ha were under coffee crops and 444 under pasture (CVC, 2012). By contrast, the DCC database

[21] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

estimated the coffee area in 2013 as 445 hectares. DCC and CVC corroborated DCC data were more accurate, since the CVC maps for this area were produced with information captured in 2000. Additionally, the information for that time was analogue, not digital, and the scale was 1:50,000, which yielded gross information that for instance, did not capture riparian forests and forest remnants. Therefore, the data from DCC was used and based on this data the values of other land uses were adjusted. Fonseca (2003) reports that from the total area in a coffee farm, 34% is under pasture and 35% under forest. In this case, analysing the different information sources, including the household survey, 51% of the area reported as coffee on the CVC map was allocated to coffee, coinciding with DCC database, and 34% was assigned to pasture and 15% to natural forest.

The pasture area was adjusted. To the value in the map, 20% was subtracted, assumed as forest remnants. Staff from the municipal Agriculture Secretary indicated that around 25 Ha were presumably converted from pasture to commercial forest in 2011. Therefore, these 25 Ha were also subtracted. Lastly, 34% of the area under coffee was added.

Concerning land use transformations, actors agreed that coffee to pasture transformations and vice versa were the dominant characteristic. CVC indicated in these Andean ecosystems in Valle del Cauca, what was possible to clear, were cleared many years ago, and remaining areas under natural forest were preserved, since high slopes or soil quality did not allow using these areas productively. The City Hall official said in 2011, new commercial forest plantations were established, but it was not possible to identify accurately if they were in *Calabazas* or in adjacent microcatchments because they did not work with hydrological boundaries. Most stakeholders agreed there was not much scope for the establishment of natural forests. However, the City Hall official expressed, it was expected the municipal government progressively acquire areas around the headwaters that supply community water systems.

In relation to restrictions on land use according to the biophysical characteristics, CVC established that area under coffee in *Calabazas* should be maximum 860 Ha, and pasture land 0 Ha (CVC, 2012). At the national level, estimations suggest that from the area used for livestock, only 50% had livestock vocation (IAvH *et al.*, 2011). However, staff from the Centre for research on sustainable agricultural production systems

(CIPAV) expressed this analysis should be done farm by farm to avoid a massive loss of livelihoods, especially for the small ranchers. Furthermore, areas with slopes up to 30% could have cattle, if they were converted to silvopastoral systems.

Colombia's government believed the country has a high potential for commercial forestry. Valle del Cauca is identified as a region with high potential for such projects. Commercial forest plantations can be developed at altitudes between 1,000 and 2,000 m (MADR and CONIF, 2009). Considering only climate and soils, in *Calabazas*, virtually 100% of the area could be planted under commercial forest. However, CVC estimated that about 139 Ha could be under this use.

Table 5-7 summarizes relevant information for the land use sector.

Table 5-7 Values for the parameters in the land use sector, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Total area[3]	S	Ha	1,388	CSI
Coffee area[3]	S	Ha	445	CSI
Commercial forest area	S	Ha	50	A
Pasture area	S	Ha	630	A
Natural forest area	S	Ha	263	A
Coffee transformation	F	$\frac{Ha}{year}$	-28	E
Coffee area demand	C	$\frac{1}{year}$	-0.02	A
Coffee profitability per area	C	$\frac{COP}{Ha * year}$	2.2E6	E
Average area coffee farm	C	Ha	2.7	CPI
Coffee profitability	S	$\frac{COP}{year}$	5.9E6	E
Maximum coffee area[4]	C	Ha	860	CSI
Maximum natural forest area[4]	C	Ha	1,388	CSI
Natural forest transformation	F	$\frac{Ha}{year}$	- 8	E
Natural forest area demand	C	$\frac{1}{year}$	-0.006	A

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Payment for environmental services	C	$\frac{COP}{Ha * year}$	0	A
Pasture transformation	F	$\frac{Ha}{year}$	36	E
Pasture area demand	C	$\frac{1}{year}$	0.026	A
Livestock profitability per area	C	$\frac{COP}{Ha * year}$	0.16E6	E
Average area livestock farm	C	Ha	17	CPI
Livestock profitability	S	$\frac{COP}{year}$	2.7E6	E
Maximum pasture area[4]	C	Ha	0	CSI
Commercial forest transformation	F	$\frac{Ha}{year}$	0	E
Commercial forest area demand	C	$\frac{1}{year}$	0.0002	A
Commercial forest profitability per area	C	$\frac{COP}{Ha * year}$	3.2E6	E
Commercial forest profitability	S	$\frac{COP}{year}$	158.5E6	E
Maximum commercial forest area	C	Ha	139	CSI

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] CDC (2012); [4] CVC (2012).

Figure 5-15 presents available historical trends at the Valle del Cauca scale, for the land use sector: Figure 5-15 (a) pasture; Figure 5-15 (b) coffee; Figure 5-15 (c) commercial forest, and Figure 5-15 (d) natural forest.

There was great disparity of information available for each of these uses. The pasture area presented an oscillatory behaviour and coffee area a declining trend. Commercial forest had a marginal growth. The information available on natural forest was practically inexistent.

Regarding pasture area, at the national level, there was a significant growth, particularly from 2005 to 2010 (IAvH *et al.*, 2011). Some explain this phenomenon with better security conditions in the countryside (Fedegan, 2006), whereas others with the bankruptcy of farmers engaged in other agricultural activities affected by free trade agreements (Suarez, 2010). Nationally, there are an estimated of 10 million hectares devoted to livestock, in land unsuitable for this use, due to their proximity to water sources, and biophysical conditions. Therefore, the livestock sector has proposed to "return to nature" these areas, changing them to a more appropriate purpose such as reforestation, or continue with livestock but under silvopastoral systems (Fedegan, 2006). However, stakeholders from this sector indicated progress in this area was restricted to isolated pilots, trying to discern, how to scale up such processes.

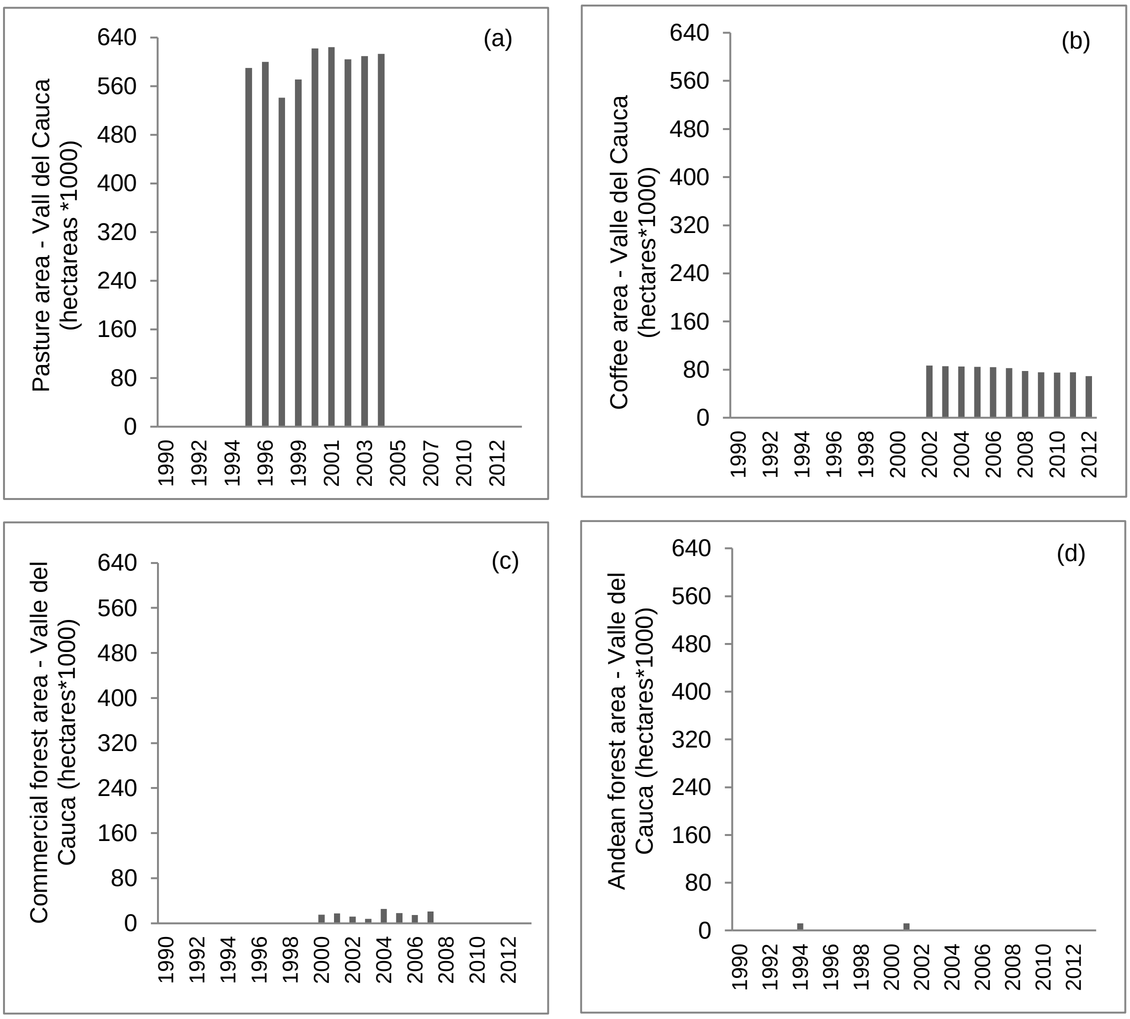


Figure 5-15 Trends of land uses for Valle del Cauca

(a) pasture; (b) coffee; (c) commercial forest; (d) natural forest.

Own, data sources: (a) Agronet (2013); (b) FNC (2014); (c) and (d) IAvH *et al.* (2011)

Concerning to coffee, the traditional coffee departments, such as Valle del Cauca, lost coffee areas in the last 10 years, primarily due to the crisis the industry is facing since the 1990s (Leibovich and Botello, 2008). DCC strategy rather than increasing the area planted was to improve productivity in the existing area, especially through renovation. Nevertheless, programs to increase coffee areas were performed sporadically.

With regards to commercial forestation, it started in Colombia at low scale in the 1940s, had its peak in the 1970s and 1980s, and then declined by failing to respond the producers´ expectations. Causes of this failure are attributed to: i) lack of roads, ii) high transport cost, iii) reduced value of timber; iv) plantations in inaccessible locations; and v) lack of information to invest (MADR, 2005). Livestock has been more desirable than forests, even in its most extensive form, except in very steep and erodible sites. In spite of this, Valle del Cauca was one of four departments in which more commercial forest was planted, with about 10% of this type of coverage in the country (IDEAM, 2010b). The government tried to increase the attractiveness of the business by offering incentives, such as the CIF (MADR, 2011). It is expected to establish 1.3 million hectares of commercial forest by 2025. This was part of a long-term state policy aimed at reducing the use of natural forests as a source of raw materials, and creating jobs based on the sustainable use and management of forests (Finagro, 2013a). However, access to land was identified as a barrier to increase the commercial forest area (CONIF, 2010). Officials from CVC expressed in Valle del Cauca, despite the incentives for commercial forest plantations, areas under this use remained rather steady since the 1990s.

In *Calabazas*, natural forest was mainly found in the upper part, in the margins of streams and near springs. Colombia lacks reliable data on forests loss, especially given the different methodologies used over the years to produce the estimates (IAvH *et al.*, 2011). In general, natural forest in the country tends to decrease. The transformations are due to the change to pasture or heterogeneous agricultural areas (IAvH *et al.*, 2011), and to the use of natural forests for timber production (MADR, 2005). 6% loss of Andean forest is an accepted figure (IDEAM, 2010b). However, staff from DCC provided for *Calabazas* a figure of 0.6%, which can be explained mainly because as indicated by CVC, most of the forest which could be cut, has already been cut. The national government had incentives for the establishment of natural forest, and set a goal of 400,000 new hectares for the period 2010 - 2014 (CONIF, 2010). However, for farmers with small homesteads, as most of those in *Calabazas*, the scope to allocate areas to conservation was limited, and access to information about these incentives difficult, which prevented progress on adoption.

5.3.4 *Stream health sector*

The stream health sector linked the population and their influence over water quality. Three parameters were selected: Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and Thermotolerant Coliforms (TTC). BOD and TSS captured the effect of domestic wastewater, coffee processing and animal husbandry. In addition, TSS was influenced by the different land uses. TTC were selected to represent point and diffuse microbial pollution from domestic wastewater, and animal husbandry. During the focus groups, participants discussed how to integrate the pollution from fertilizers, but there was insufficient knowledge on the type and scale of the fertilizers used. It was thought, since most coffee farms in *Calabazas* were small, people would not have extensive use of these inputs. Therefore, it was agreed to leave out this issue. The stream health sector was divided in three modules as explained below.

BOD module

The BOD module took into account the contributions of people, pigs and coffee processing, and estimated annual loads to the stream. In addition, it estimated concentration in mg/l, by considering stream flow, and a self-purification effect. BOD contributions from each of the selected sources could be reduced by the implementation of Best Management Practices (BMPs). For example: i) individual secondary treatment systems for domestic wastewater ii) ecological coffee processing systems; iii) bio-digesters for pig excreta. The NFC implemented some of these strategies in some farms, as part of PFP. Figure 5-16 includes the structure for the BOD module in the stream health sector, factors that made the structure, their numerical values for 2013, and the sources of information.

Table 5-8 provides another summary of this module. Factors from the literature were used as BOD loads for the different sources, and the scale of these sources was taken from results of the household survey carried out as part of this research (Chapter 4).

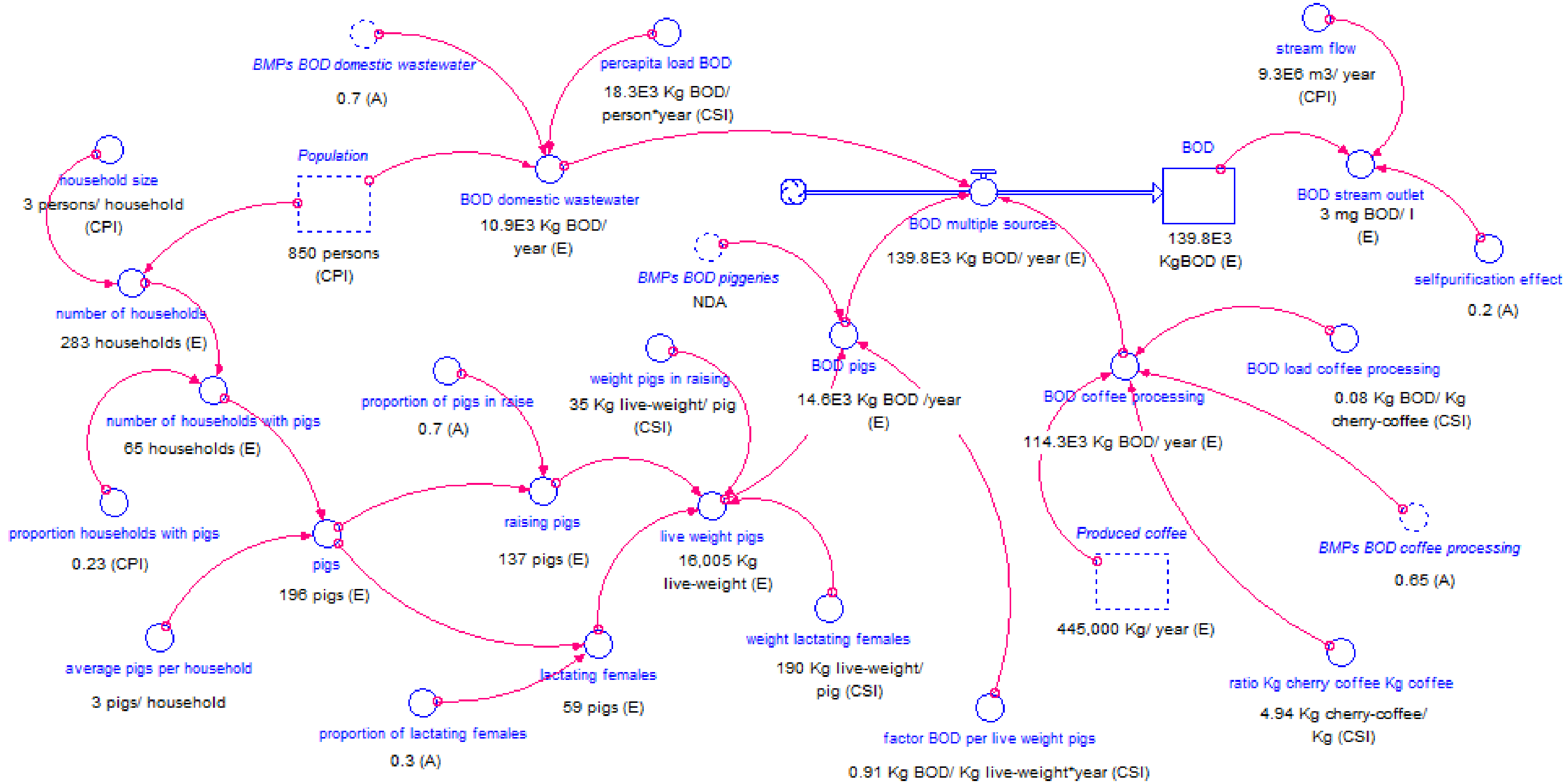


Figure 5-16 Structure of the BOD module in the stream health sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[22]

[22] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-8 Values for the parameters in the stream health sector – BOD, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
BOD stream outlet	C	*mg/l*	3	E
Self-purification effect	C	*dimensionless*	0.2	A
Stream flow	C	$\frac{m^3}{year}$	9.3E6	CPI
BOD	S	$KgBOD$	139.8E3	E
BOD multiple sources	F	$\frac{KgBOD}{year}$	139.8E3	E
BOD domestic wastewater	C	$\frac{KgBOD}{year}$	10.9E3	E
Population	S	*persons*	850	CPI
Per capita load BOD[1]	C	$\frac{KgBOD}{person * year}$	18.3E3	CSI
BMPs BOD domestic wastewater[2]	C	*dimensionless*	0.7	A
BOD pigs	C	$\frac{KgBOD}{year}$	14.6E3	E
Factor BOD per live-weight pigs[3]	C	$\frac{KgBOD}{Kglive - weight * year}$	0.91	CSI
Live-weight pigs*	C	*Kg live-weight*	16,005	E
Weight lactating females[3]	C	$\frac{Kglive - weight}{pig}$	190	CSI
Lactating females*	C	*pigs*	59	E
Proportion of lactating females	C	*dimensionless*	0.3	A
Weight pigs in raising[3]	C	$\frac{Kglive - weight}{pig}$	35	CSI
Raising pigs*	C	*pigs*	137	E
Proportion of pigs in raise	C	*dimensionless*	0.7	A
Pigs*	C	*pigs*	196	E
Number of households* with pigs	C	*Households*	65	E
Proportion of households with pigs	C	*dimensionless*	0.23	CPI
Average pigs per household	C	$\frac{pigs}{household}$	3	CPI
Household size	C	$\frac{persons}{household}$	3	CPI

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Number of households	C	*households*	283	CPI
BOD coffee processing	C	$\frac{KgBOD}{year}$	114.3E3	E
Produced coffee*	S	$\frac{Kg}{year}$	445,000	E
BOD load coffee processing[4]	C	$\frac{Kg\ BOD}{Kg\ cherry-\ coffee}$	0.08	CSI
Ratio Kg cherry coffee Kg coffee[5]	C	$\frac{Kg\ cherry-coffee}{kg}$	4.94	CSI
BMPs BOD coffee processing[6]	C	*dimensionless*	0.65	A

[1] S: Stock: F: Flow; C: Converter. CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] IDEAM (2010a); [4] 45% of the population had secondary treatment systems that remove 80% of the BOD load (von Sperling (2007)); [5] Minambiente (2002); [6] Orozco (2003); [7] Montilla *et al.* (2008)); [8] 50% of coffee is processed under ecological processing that reduce 70% of the BOD load (Cenicafé (2011)).
* Values corresponding to the whole catchment.

Water quality in *Calabazas* was not monitored before this research; therefore, historical data on this parameter were not available. Results from the stream water survey showed that BOD at the catchment outlet was under the detection levels of the method for both rainy and dry season (< 3 mg/l). The low population density, the generous stream flow, high slope favouring self-purification, and the implementation of strategies such as ecological coffee processing, and individual sanitation undertaken by DCC could explain the low BOD levels. Data from the water quality monitoring obtained through the stream water survey reported in Chapter 4, were used to give an indication of the dilution and self-purification capacity of the source and adjust the estimates to the concentrations of BOD measured in the field. However, there is a high degree of uncertainty in the estimates due to the unit loads per activity based on secondary information sources, and the many assumptions made to obtain these estimates.

TSS module

The TSS module took into account the contributions of people, pigs, coffee processing, and erosion from coffee, commercial forest and livestock areas. It estimated annual loads to the stream. In addition, it estimated the concentration in mg/l, by considering stream flow. Factors from the literature were used as TSS loads from the sources considered, and the scales of these sources were taken from the household survey (Chapter 4). Figure 5-17 shows the Stella structure for this module, including factors, numerical values for the year 2013, and their information sources.

Table 5-9 summarizes information about this module. Reduction factors from BMPs in brackets were not included in the estimations, since those are potential managerial practices but were not in place.

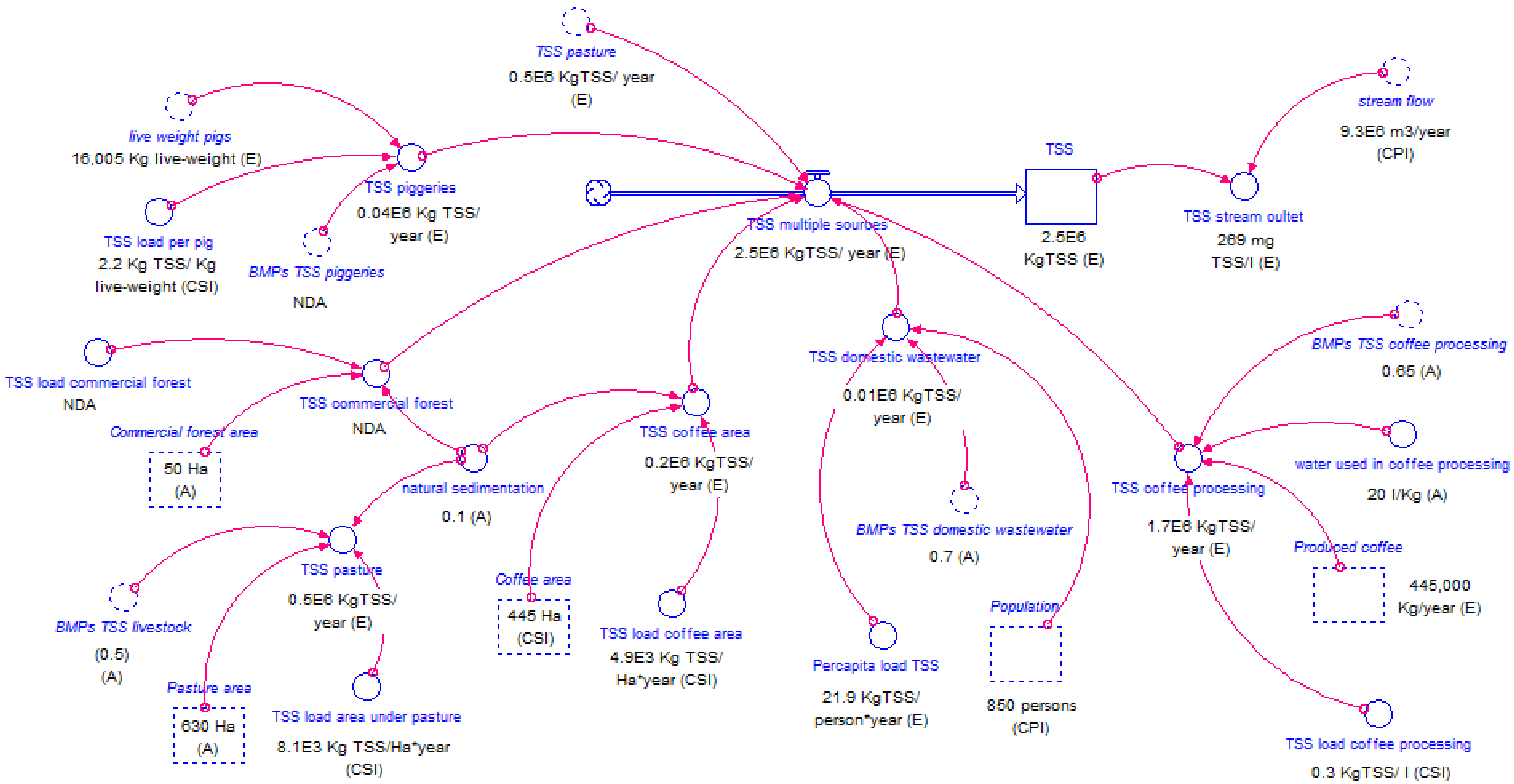


Figure 5-17 Structure of the TSS module in the stream health sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[23]

[23] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-9 Values for the parameters in the stream health sector – TSS, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
TSS stream outlet	C	*mg/l*	269	E
Stream flow	C	$\frac{m^3}{year}$	9.3E6	CPI
TSS	S	$KgTSS$	2.5E6	E
TSS multiple sources	F	$\frac{KgTSS}{year}$	2.5E6	E
TSS domestic wastewater	C	$\frac{KgTSS}{year}$	0.01E6	E
Population	S	persons	850	CPI
Per capita load TSS[3]	C	$\frac{KgTSS}{person * year}$	21.9	CSI
BMPs TSS domestic wastewater[4]	C	dimensionless	0.7	A
TSS piggeries	C	$\frac{KgTSS}{year}$	0.04E6	E
TSS load per pig[5]	C	$\frac{KgTSS}{live - weight * year}$	2.2	CSI
Live weight pigs	C	Kg live-weight	16,005	E
BMPs TSS piggeries	C	dimensionless	No data available	NDA
TSS commercial forest	C	$\frac{KgTSS}{year}$	Insufficient data for estimation	NDA
TSS load commercial forest	C	$\frac{KgTSS}{Ha * year}$	No data available	NDA
Commercial forest area	C	Ha	50	A
TSS coffee processing	C	$\frac{KgTSS}{year}$	1.7E6	E
TSS load coffee processing[6]	C	$\frac{KgTSS}{l}$	0.3	CSI
BMPs TSS coffee processing	C	dimensionless	0.65	A
Produced coffee	C	$\frac{Kg}{year}$	445,000	E
Water volume used processing[7]	C	$\frac{l}{Kg}$	20	A
TSS coffee area	C	$\frac{KgTSS}{year}$	0.2E6	E

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
TSS load coffee area[8]	C	$\frac{KgTSS}{Ha * year}$	4.9E3	CSI
Coffee area[9]	S	Ha	445	CSI
Natural sedimentation	C	dimensionless	0.1	A
TSS pasture	C	$\frac{KgTSS}{year}$	0.5E6	E
TSS load area under pasture[10]	C	$\frac{KgTSS}{Ha * year}$	8.1E3	CSI
Pasture area	S	Ha	630	A
BMPs TSS livestock	C	dimensionless	(0.5)	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] von Sperling (2007)[4] 45% of the population had secondary treatment systems, removing 80% of TSS (von Sperling, 2007) [5] Minambiente (2002); [6] Molina and Villatoro (2006); [7] 50% of coffee is processed under ecological processing that reduce 70% of TSS (Cenicafé, 2011); [8] Cenicafé (2011); [9]CDC (2012) [10] Chará *et al.* (2011).

Historical data were not available on TSS for *Calabazas*. The drinking water survey showed that TSS at the catchment outlet was in average 2.4 mg/l (Chapter 4). This figure is substantially lower compared to the values obtained using the model equations (269 mg/l). This is related to the higher degree of uncertainty associated to the TSS loads per activity taken from the literature, and the fact that quantifications included dilution but not in-stream sedimentation and other depuration processes, which the group lacked of knowledge to introduce.

TTC module

The TTC module used the contributions of people (wastewater), pigs (slurry) and livestock (TTC proportion from cows faeces deposited in the meadows, which can reach water sources). TTC loads from these sources were estimated as annual loads to the stream. In addition, estimates of TTC concentration were produced by considering stream flow. Factors from the literature were used as pathogen loads from these different sources, and the scales of these sources were taken from the household survey (Chapter 4). The TTC contributions from these activities could be reduced by implementing BMPs (e.g. individual secondary treatment facilities, silvopastoral systems and bio-digesters). Figure 5-18 and Table 5-10 summarize model structure and the relevant information regarding this module.

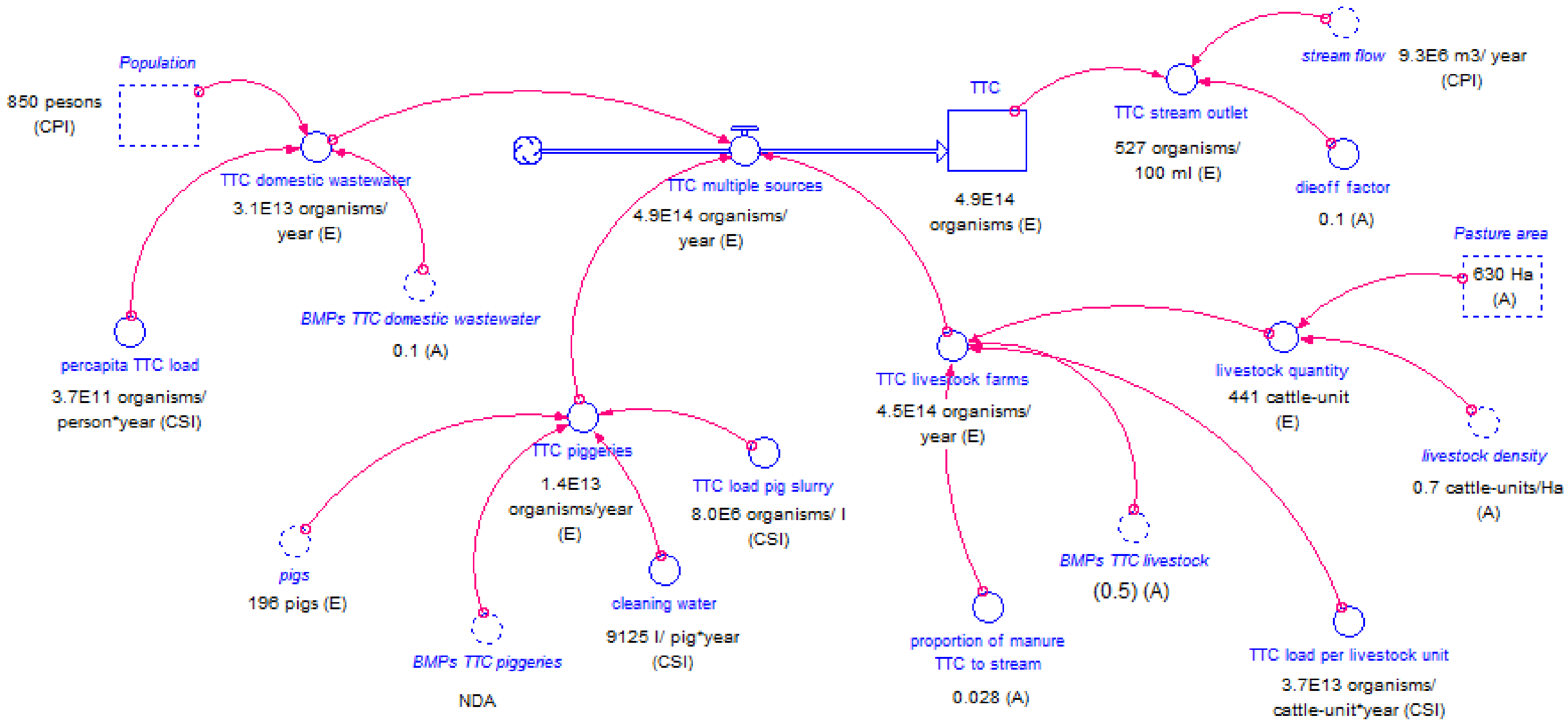


Figure 5-18 Structure of the TTC module in the stream health sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[24]

[24] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-10 Values for the parameters in the stream health sector – TTC, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
TTC stream outlet	C	$\frac{organisms}{100ml}$	527	E
Stream flow	C	$\frac{m^3}{year}$	9.3E6	CPI
Die-off factor	C	*dimensionless*	0.1	E
TTC	S	$organisms$	4.9E14	E
TTC multiple sources	F	$\frac{organisms}{year}$	4.9E14	E
TTC domestic wastewater	C	$\frac{organisms}{year}$	3.1E13	E
Population	S	*persons*	850	CPI
Per capita TTC load[3]	C	$\frac{organism}{person * year}$	3.7E11	CSI
BMPs TTC domestic wastewater	C	*dimensionless*	0.1	A
TTC piggeries	C	$\frac{organisms}{year}$	1.4E13	E
TTC load pig slurry[4]	C	$\frac{organisms}{l}$	8.0E6	CSI
Cleaning water [5]	C	$\frac{l}{pig * year}$	9,125	CSI
Pigs	C	*pigs*	196	E
BMPs TTC piggeries	C	*dimensionless*	No data available	NDA
TTC livestock farms	C	$\frac{organisms}{year}$	4.5E14	E
TTC load per livestock unit[6]	C	$\frac{organisms}{cattle - unit * year}$	3.7E13	CSI
Livestock quantity	C	*cattle-units*	441	E
Livestock density	C	*cattle-unit/Ha*	0.7	A
Livestock area	S	*Ha*	630	A
Proportion manure to stream	C	*dimensionless*	0.028	A
BMPs TTC livestock	C	*dimensionless*	(0.5)	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] von Sperling (2007); IDEAM (2010a); [4] Bicudo and Svoboda (1995); Rufete *et al.* (2006); Massé *et al.* (2011); Chartier *et al.* (2014); [5] Minambiente (2002) [6] USDA and NRCS (2012).

Historical data were not available on TTC for *Calabazas* either. TTC at the catchment outlet measured in the stream water survey was in average 133 organisms/100ml (Chapter 4), lower to that obtained with the model estimations (527 organisms/100ml). The difference is also explained with the use of unit loads per activity from the literature, and the complexity of transport and survival of bacteria in the environment (USDA and NRCS, 2012; EPA, 2013).

5.3.5 Human health sector

Humans may be exposed to waterborne pathogens via ingestion of drinking water. Other routes of exposure are not the scope of this model. Surface waters may become contaminated by pathogens from agricultural runoff and domestic wastewater discharges (EPA, 2013). Inadequacies at water system facilities can lead to waterborne outbreaks associated with drinking water (USDA and NRCS, 2012), although dilution and die-off can help mitigate the possibility of illness (EPA, 2013).

The health sector in the participatory model was not extensively developed during the focus groups. The initial structure produced by the group linked the concentration of TTC in the water body with a level of risk of enteric diseases, cases of illness, and the reported cases, with the understanding that the notification rate was low (Chapter 4). After suggestions from some experts and individual research on the literature, the final structure of the health sector is shown in Figure 5-19, together with the numerical values of the factors for the year 2013, and their information sources.

The health sector was linked to the population, stream health and management sectors. The link with the population sector was through the population stock, which was the number of individuals at risk of enteric disease, and the link to the management sector was the coverage of improved water systems, which determined the susceptible population. The link to the stream health sector was through the concentration of TTC at the stream.

The human health sector was prepared based on the Quantitative Microbial Risk Assessment (QMRA) methodology by Haas *et al.* (1999) and adaptations for developing countries by Howard *et al.* (2006). QMRA combines available information on exposure and dose–response to produce estimates of the disease burden associated with exposure to pathogens (WHO, 2004).

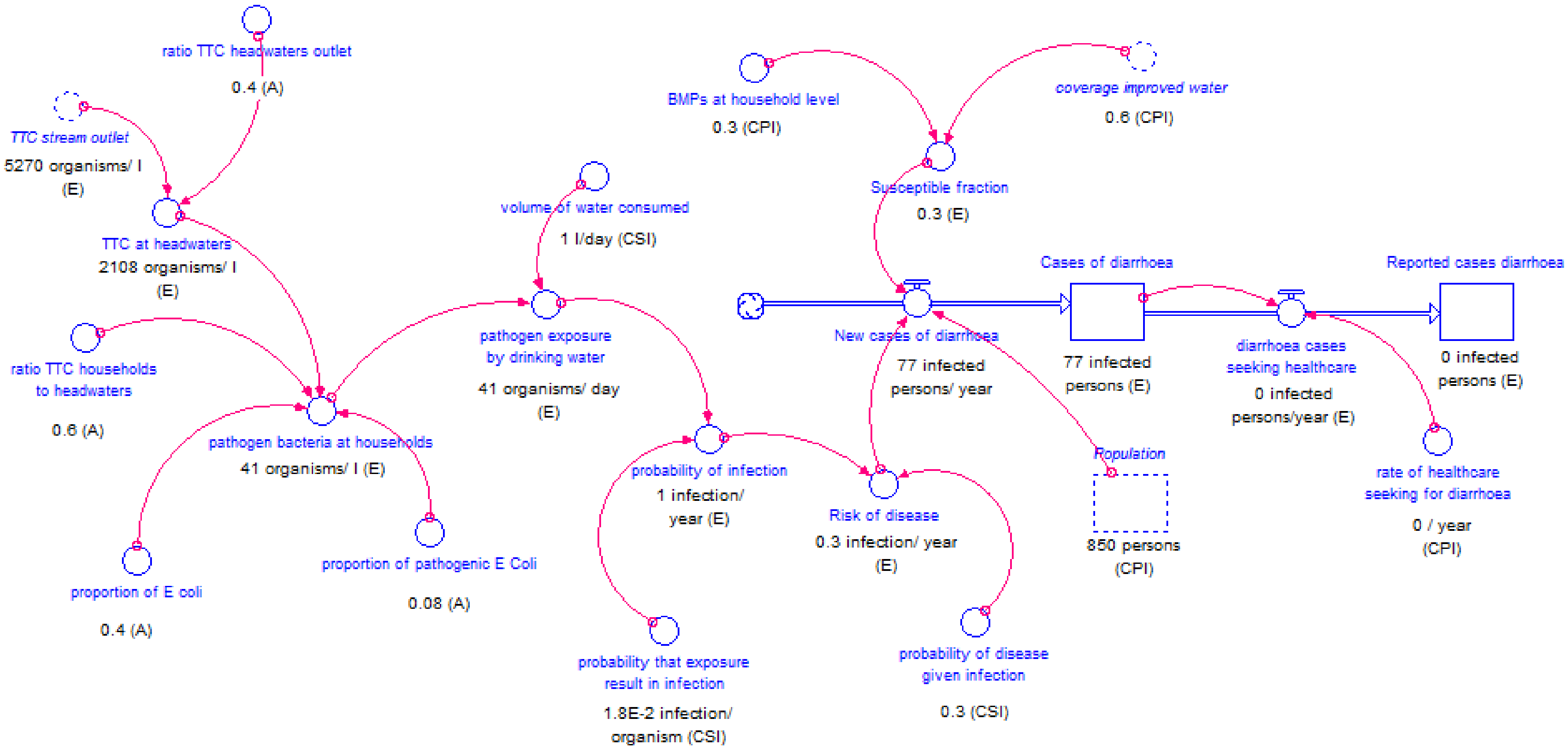


Figure 5-19 Structure of the human health sector produced using the Stella software, values of the parameters for the year 2013, and sources of information[25]

[25] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

The stocks cases of diarrhoea and reported cases were connected by disease cases seeking medical care, which were influenced by a notification rate. The diarrhoea cases stock increased by a flow of new cases. New cases depended on the population and the risk of disease. Risk of disease depended in turn on the probability of infection and probability of disease, given infection. The probability of infection was influenced by exposure by drinking water and the probability of exposure results in infection (dose-response). These factors were taken from the literature (Haas *et al.*, 1999; Howard *et al.*, 2006).

Exposure due to the consumption of drinking water depended on the volume of water ingested and the concentration of pathogens in this water. A distinction between the concentration of pathogens in homes and concentration at headwaters was made, based on results from the drinking water survey (Chapter 4), which suggested a decrease in this concentration during transport of water between these two points in *Calabazas*. Additionally, families could reduce the concentration of pathogens by implementing BMPs.

Regarding the links between TTC and pathogen bacteria in the stream, TTC are not pathogens, but an indicator of the possible presence of pathogens in water. Due to the difficulty of detecting specific pathogenic organisms in the water, the use of indicators such as TTC has been considered a more efficient and less expensive alternative to signal the potential presence of pathogens in water. It is recognized that in many cases there is no precise correlation between the presence of pathogens and indicators, because among them there are differences in transport and survival abilities. Despite this, Faecal Coliforms or TTC have been used as indicators of bacterial contamination in catchments associated with contamination by faeces of animals or people and to signal the risk of enteric diseases transmitted through water (WHO, 2004; von Sperling, 2007; USDA and NRCS, 2012; EPA, 2013). WHO (2004) has indicated that *E. coli*, or TTC are appropriate indicators for the presence/absence in water sources for human consumption of pathogen bacteria such as: *Campylobacter spp*, *E. coli*, *Salmonella spp*. and *Shigella spp*. The indicator bacteria are associated with some pathogenic bacteria causing diarrhoea, but not with virus, or protozoa which also cause the disease.

The model related level of the indicator (TTC) and the potential pathogens based on suggestions from QMRA. Only pathogenic *E. coli*, was considered as recommended by

Howard *et al.* (2006), since the stream health sector only provided data on TTC. However, it is recommended using reference pathogens for virus and protozoa as well, in order to produce better estimations (Haas *et al.*, 1999). Factors were included to estimate the proportion of TTC that were *E. coli* and the proportion of *E. Coli* that were pathogenic. Estimations from QMRA can be based on indicator organisms by the recognition of the limited availability of adequate data on pathogens occurrence, especially in developing countries (Howard *et al.*, 2006). The susceptible population was calculated from known rates of access to improved water supply in *Calabazas* from household survey results. Coverage for 2013 was 60%.

Model estimates yielded 77 cases of diarrhoea in 2013. This would be a diarrhoea prevalence of 9%. Reports of prevalence from *Riofrío* hospital for the districts belonging to the municipality for 2013 were between 4% and 8% (Sanchez, 2014). This prevalence were from reported cases. Data from the household survey indicate a prevalence of diarrhoea during the rainy season sampling (March - May 2013) of 4.4% and during the dry season sampling (July - Aug 2013) of 0.3 %. This was consistent with data from national surveillance indicating that cases of diarrhoea are higher in the first semester of the year, associated with the seasonal weather (Gutiérrez *et al*., 2005). In *Calabazas*, during 8 weeks of monitoring 16 cases occurred. Making a rule of thumb, one could say that 104 cases may arise during the year, figure slightly higher than that estimated by the model (77 cases). However, the reported diarrhoea in the survey, included cases due to all pathogens (bacteria, viruses and protozoa), while the model estimates were only associated with cases caused by bacteria. Additionally, the reported cases (cases for which medical care is sought) by the model in 2013 were 0, reflecting the rate of healthcare seeking for diarrhoea of 0, according to results from the household survey. Table 5-11 summarizes information about the human health sector for 2013.

Table 5-11 Values for the parameters in the human health sector, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Reported cases of diarrhoea	S	$infected\ persons$	0	E
Diarrhoea cases seeking healthcare	F	$\frac{infected\ persons}{year}$	0	E
Rate of healthcare seeking for diarrhoea	C	$\frac{1}{year}$	0	CPI

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Cases of diarrhoea	S	*infected persons*	77	E
New cases of diarrhoea	F	$\frac{infected\ persons}{year}$	77	E
BMPs at household level	C	*dimensionless*	0.3	CPI
Susceptible fraction	C	*dimensionless*	0.3	E
Coverage improved water	C	*dimensionless*	0.6	CPI
Population	S	*persons*	850	CPI
Risk of disease	C	$\frac{infection}{year}$	0.3	E
Probability of disease given infection [3]	C	*dimensionless*	0.3	CSI
Probability of infection	C	$\frac{infection}{year}$	1	E
Probability that exposure result in infection [3]	C	$\frac{infection}{organism}$	$1.8*10^{-2}$	CSI
Pathogen exposure by drinking water	C	$\frac{organisms}{day}$	41	E
Volume of water consumed [3]	C	$\frac{l}{day}$	1	CSI
Pathogen bacteria at households	C	$\frac{organisms}{l}$	41	E
Proportion of pathogenic E. Coli [1]	C	*dimensionless*	0.08	A
Proportion of E. Coli	C	*dimensionless*	0.4	A
Ratio TTC households to headwaters	C	*dimensionless*	0.6	A
TTC at headwaters	C	$\frac{organisms}{l}$	2,108	E
Ratio TTC headwaters outlet	C	*dimensionless*	0.4	A
TTC stream outlet	C	$\frac{organisms}{l}$	5,270	E

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] Haas *et al.* (1999); WHO (2004); Howard *et al.* (2006)

5.3.6 Management sector

The management sector included one stock that represents the available budget from institutions and inhabitants to invest in catchment health and human health. The budget increased by a resources flow, fed by funding from institutions and population. The budget stock decreased by a flow of investments made through different initiatives towards catchment and human health and wellbeing. This sector had feedback relationships with the economic sector, and influenced land use, stream health and human health sectors.

Figure 5-20 includes representation of the factors that were identified as important to define the management sector for the studied microcatchment, their numerical values for 2013, with their corresponding codes indicating the information sources.

Table 5-12 provides another summary of information on this model sector.

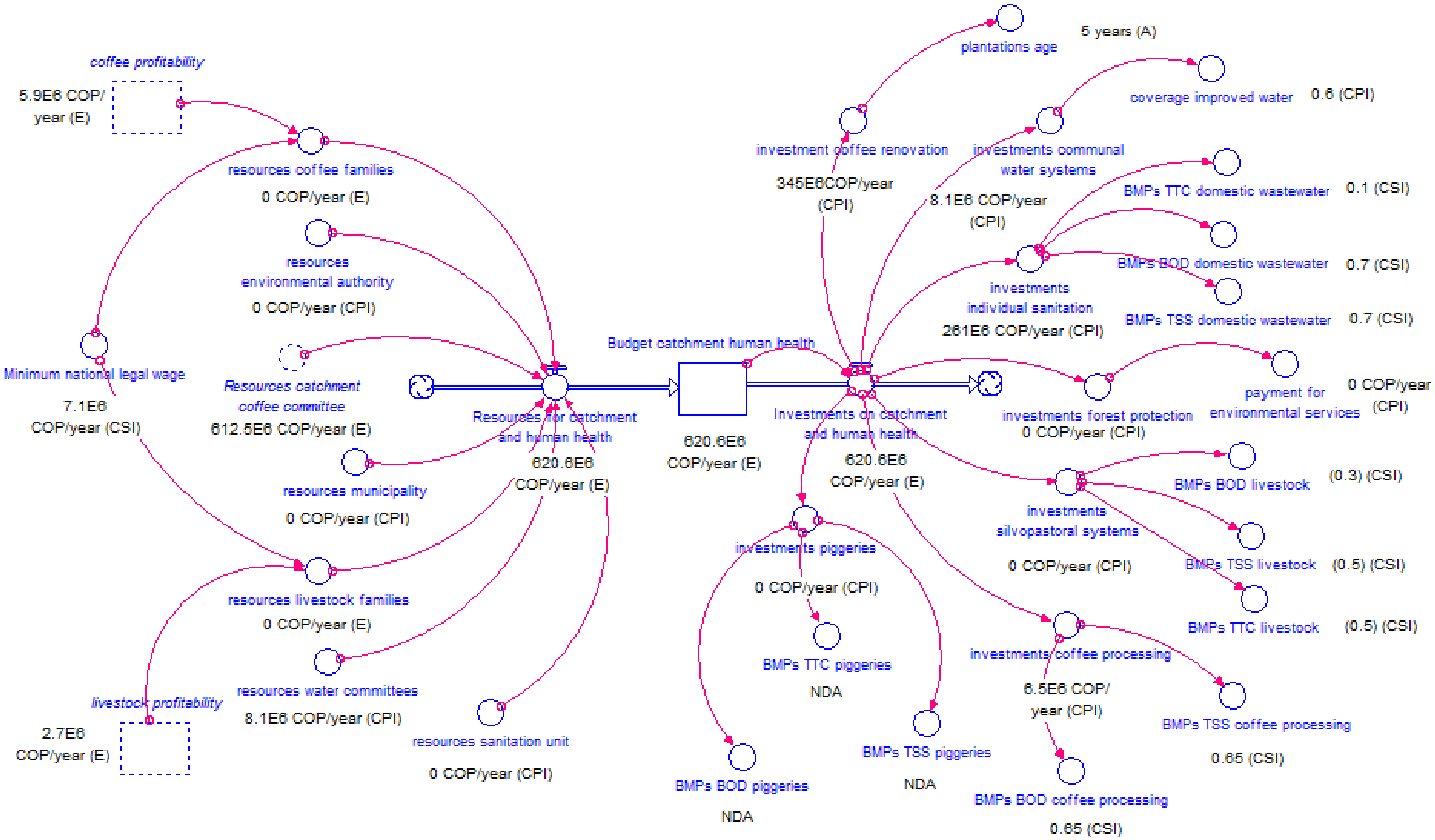


Figure 5-20 Structure of the management sector produced using the Stella software, values of the parameters for the year 2013, and sources of information [26]

[26] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M).

Table 5-12 Values for the parameters in the management sector, year 2013

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Budget catchment health and human health	S	COP	620.6E6	E
Resources for catchment health and human health	F	$\frac{COP}{year}$	620.6E6	E
Resources coffee families	C	$\frac{COP}{year}$	0	E
Coffee profitability	S	$\frac{COP}{year}$	5.9E6	E
Minimum national legal wage[3]	C	$\frac{COP}{year}$	7.1E6	CSI
Resources livestock families	C	$\frac{COP}{year}$	0	E
Livestock profitability	S	$\frac{COP}{year}$	2.7E6	E
Resources Environmental Authority	C	$\frac{COP}{year}$	0	CPI
Resources catchment coffee committee	C	$\frac{COP}{year}$	612.5E6	E
Resources municipality	C	$\frac{COP}{year}$	0	0
Resources water committees	C	$\frac{COP}{year}$	8.1E6	CPI
Resources sanitation unit	C	$\frac{COP}{year}$	0	CPI
Investment on catchment and human health	C	$\frac{COP}{year}$	620.6E6	E
Investments coffee renovation	C	$\frac{COP}{year}$	345E6	CPI
Plantations age	C	$years$	5	A
Investments communal water systems	C	$\frac{COP}{year}$	8.1E6	CPI
Investments individual sanitation	C	$\frac{COP}{year}$	261E6	CPI
BMPs TTC domestic wastewater[4]	C	$dimensionless$	0.1	A
BMPs BOD domestic wastewater[4]	C	$dimensionless$	0.7	A
BMPs TSS domestic wastewater[4]	C	$dimensionless$	0.7	A
Investments in forest protection	C	$\frac{COP}{year}$	0	CPI
Payment for environmental services	C	$\frac{COP}{year}$	0	CPI

Name	Type of object[1]	Units	Initial condition	Type of data source[2]
Investments piggeries	C	$\frac{COP}{year}$	0	CPI
BMPs TTC piggeries	C	*dimensionless*	No data available	NDA
BMPs BOD piggeries	C	*dimensionless*	No data available	NDA
BMPs TSS piggeries	C	*dimensionless*	No data available	NDA
Investments silvopastoral systems	C	$\frac{COP}{year}$	0	CPI
BMPs TTC livestock[5]	C	*dimensionless*	0.5	A
BMPs BOD livestock[6]	C	*dimensionless*	0.3	A
BMPs TSS livestock[7]	C	*dimensionless*	0.5	A
Investments coffee processing	C	$\frac{COP}{year}$	6.5E6	CPI
BMPs BOD coffee processing[8]	C	*dimensionless*	0.65	A
BMPs TSS coffee processing[9]	C	*dimensionless*	0.65	A

[1] S: Stock: F: Flow; C: Converter. [2] CPI: Values obtained from collection of primary information. CSI: Values obtained from collection of secondary data and literature sources. A: Values assumed after review of literature sources, consultation with stakeholders trough semi-structured interviews or both. E: Values estimated from other model parameters (see Appendix M). [3] Presidencia (2012); [4] 45% of the population had secondary treatment systems that remove 80% of the BOD load (von Sperling, 2007); [5] USDA and NRCS (2012): [6] Chará *et al.* (2011); [7] CIPAV (2013); [8] 50% of coffee is processed under ecological processing, reducing 70% of BOD and TSS loads (Cenicafé, 2011); [9] Cenicafé (2011).

On the side of the institutions, resources were potentially received from DCC, the municipality, the Sanitation Unit (SU) and CVC. During 2013, DCC was almost the only institution that invested in the microcatchment. Water committees also undertook investments using resources from water tariffs. The available resources by DCC came from the FoNC, estimated in the economic sector.

On the side of the community, coffee growers and livestock keepers made investments, depending on the profitability of these activities. Profitability was estimated in the economic sector and compared to the legal monthly minimum wage. Investments were made only if there was surplus, i.e., if the profits exceed the minimum wage. In 2013, profitability for coffee families was 5.9 million COPs and for ranching families was 2.7 million COP. The minimum wage for 2013 was 7.1 million COP. Thus, according to the model assumptions, profitability of productive activities was not enough to cover living costs for families, and therefore there were no surpluses for investment in any of the areas considered.

Information provided by the communities and professionals suggested that families mainly contributed time and labour in some of these initiatives. For example, performing maintenance to community water systems, making excavations for the construction of sanitation systems, and receiving training on environmental issues. However, investments in specie were not included in the model. On the other hand, given that, as explained in Section 4.3.1, income information was known to be a culturally sensitive issue locally, information about remittances from relatives abroad was not captured. Therefore, the possibility of remittances used to make investments for human and catchment health was not considered.

The Budget stock reduced by the investments made in the microcatchment. The investments were towards: i) renovation of coffee plantations ii) ecological processing; iii) individual sanitation systems iv) systems for digestion of pig manure, v) water supply systems vi) forest protection, and vii) silvopastoral systems.

Investments in coffee renovation helped keep coffee plantations in an average age that prevent declines in productivity. Renovation programs had taken place in *Calabazas* in previous years through initiatives like PFP. This strategy aimed at achieving productive and resistant to rust coffee farming, because only *Castillo* variety was planted. Investments of PFP in renovation of coffee plantations in 2013 were 345 million of COP, with 230 beneficiaries.

Ecological coffee processing systems reduced BOD and TSS loads from this activity to water bodies. The Coffee Research Centre (Cenicafé) ascribed to the NFC, defined ecological processing as a philosophy of better management of water and coffee processing by-products. In 2013, PFP built 60 pits with ceilings at a cost of 6.5 million COP. These pits are a component of ecological coffee processing. The resulting residue from removing coffee pulp is transported under dry conditions to the pits and stored for six months to decompose and the by-product can be used as organic fertilizer within the farm. This practice reduces around 70% of the potential contamination to water sources compared to traditional coffee processing (Cenicafé, 2011).

Individual sanitation systems with secondary treatment installed in *Calabazas* (Chapter 4) could achieve reductions in BOD (80%), TSS (80%), and some TTC (90 – 99%) loads to water bodies (von Sperling, 2007). With PFP, 58 individual domestic wastewater treatment systems were built in 2012 and 2013, at a cost of 261 million COP. Digesters to treat pig manure also contribute to reductions in BOD, TSS and TTC loads related to pigs rearing. However, these systems were not in place in *Calabazas*.

Investments in silvopastoral systems improve profitability and environmental performance of livestock farming. With these systems, grassland productivity is improved, allowing increasing the density of cattle. It also can reduce the load of contaminants to water bodies: BOD (70%) (Chará *et al.*, 2011), TSS (50%) (CIPAV, 2013), and TTC (20 – 90%) (USDA and NRCS, 2012). Fedegan and CIPAV were investigating models to improve livestock in Colombia, including silvopastoral systems. However, the level of implementation was low. Furthermore, as an organization, Fedegan was less developed compared to the NFC. In *Calabazas*, Fedegan through Cogancevalle had no affiliates. Therefore, there were no silvopastoral systems and neither possibilities of their implementation in the medium term.

Investments in water supply help maintain systems operational, care for headwaters, implement disinfection systems and increase service coverage, reducing the population susceptible to diarrhoea. As presented in Chapter 4, *Calabazas* had four communal service providers that supplied 60% of the population. The majority of these systems charged water tariffs, in average 4,000 COP per month, in 2013. However, for most of the systems, except Acuafenicia, these resources were insufficient, preventing them to undertake water disinfection, and increase coverage.

In the model, resources for forest protection are used to fund PES, which should be equivalent to the opportunity cost of keeping (or changing) natural forest instead of having coffee or livestock. This was linked to the land use sector affecting the rate of protective forest transformation. Since May 2013, the Ministry of Environment and Sustainable Development issued Act 0953, which states the conditions for territorial authorities to fund PES, and to acquire land in areas of strategic importance for the conservation of water resources (MADS, 2013). This rule seeks to operationalize a previous standard, which states that these authorities should allocate at least 1% of their income for the acquisition of land or PES. However, stakeholders from CVC believed the trend will be that the state acquires the properties of interest gradually, and no PES because effective mechanisms to ensure sufficient and constant availability of resources it demands have not been found. For this reason, it was not believed PES would become part of the livelihoods of rural communities in the short term. The municipal budget for the category of microcatchments preservation for 2013 was 30 million COP. However, there was no evidence that some of that money were used in *Calabazas*.

There was no historical information available regarding investments by institutions in *Calabazas*. However, this stock may have an oscillatory behaviour, subject to economic dynamics and decisions of the institutions to allocate resources between the regions under their jurisdiction, according to their particular prioritization criteria. For example, the high investments by DCC in *Calabazas* from 2011 to 2014 were due to its selection as a pilot project for PFP, which had international cooperation resources. As explained in Sections 1.3 and 3.3.2, PFP involved interventions in various aspects to improve the quality of life of coffee farmers, including renovation of coffee plantations, sanitation, coffee processing, and protection of sources, among others.

5.4 Discussion

SD principles and tools were used to produce a semi-quantitative participatory model that integrated socioeconomic and environmental factors to improve the understanding of the linkages between catchment health and human health and wellbeing in *Calabazas*, using the conceptual framework of IWRM-EcoHealth. Model formulation contributed to understanding of the system, by elucidating the following premises stated at the beginning of the process:

Coffee growing is not profitable and wellbeing of farmers is threatened

Coffee growing was the main employment generating activity in *Calabazas*. For this activity, low prices in the international market and the revaluation policy of the national government meant low profit and incomes for farmers below the legal minimum wage in the country. However, this was not the only economic activity in crisis; livestock farming also had low profitability, particularly milk. One of the reasons was the sign of free trade agreements that loaded the domestic market with foreign products at lower cost to the detriment of local producers. For both coffee and livestock farming, production costs were above selling costs, preventing farmers to have an adequate standard of living from their livelihoods. In Colombia, the coffee crisis bottomed out in 2013 and there was alarm over the potential loss of livelihoods for more than 560,000 coffee families (Robledo, 2007; Cano *et al.*, 2012). A similar situation was experienced by those engaged in the dairy sector (Suarez, 2010). This case is one of many examples worldwide that shows how the protection of poor peasants from the implications of free trade is becoming an imperative (Malik, 2013).

The external factors (to the microcatchment) such as free trade, international prices, revaluation, and production costs were exacerbated by the small size of the farms. In Colombia, land tenure is a structural problem. Access to land has been a factor of violence, hoarding and speculation, where 1.15% of the population owns 52% of the land (PNUD, 2011). In *Calabazas*, coffee and livestock plots were below the size that allow generating sufficient income to ensure the satisfaction of the basic needs of a family (García and Ramírez, 2002; Fedegan, 2013c). Moreover, the low productivity of livestock and coffee farming was an additional factor in the low profit. Instead of increasing support to the small farmers livelihoods, the National government allocated taxpayer resources to promote commercial forestry, which had high profitability compared to coffee and livestock farming, but was developed by a foreign multinational company, and the higher profit was derived from more land and government subsidies.

The small farm sizes also limited employment opportunities to almost one family member. This influenced the population sector, in which the dominant phenomenon was emigration due to the inability to meet basic needs. The population showed a tendency to aging and the number of working-age people, particularly women, was reducing. *Calabazas* was an example of the emigration phenomenon in the coffee region in Colombia (DNP, 2007; Narvaez and Velasquez, 2009; Murillo, 2010), and in general in the rural areas of the country, that was preventing achievements in human development (PNUD, 2011). Emigration from the rural areas is a general tendency in low and middle-income countries around the world, due to lack of opportunities and under investment in the countryside (Marmot *et al.*, 2008; Malik, 2013). This lack of opportunities and under investment was also evidenced in Section 4.4.1, where the behaviour of the social determinants of health in *Calabazas* was contrasted to the behaviour of those determinants either for the urban areas of Colombia or for the country as a whole (national averages).

If coffee farming is not profitable neither the National Coffee Fund nor the farmers have resources to invest in more sustainable ways of interacting with the environment

The management sector integrated strategies of different actors, such as local government, CVC, DCC, and water service providers, among others, to address the factors that contributed to catchment health and human health and wellbeing. Results proved the low investment capacity of farmers due to their diminished income from the poor profitability of their livelihoods. Results also showed the decrease of revenues to the FoNC through the CC, which implied the institution no longer depended on their income from coffee sales for investment in rural areas, making state resources and international aid the main source of programs' funding. This external support however, is not steady, and as noted by Batterman *et al.* (2009), has consequences for the ability to decide how to invest the resources, leading to address agencies´ mandates instead of communities´ needs.

The coffee industry generates a significant impact on water sources

Among the pollution sources to the stream, obtained based on loads from the literature and scale of the pollution sources from primary data, coffee processing appeared the largest generator of BOD and TSS loads, compared with the contributions of domestic wastewater, piggeries, and land use forms (Figure 5-16 and Figure 5-17). However, accounting for dilution and self-purification, BOD concentrations reduced to levels in the category of fresh water with low pollution (Chapman *et al.*, 1996) (Figure 5-16). For TSS, the model estimates were greater than those measured in the field, due to the higher degree of uncertainty associated to the TSS loads per activity taken from the literature, and the fact that model estimations did not account for in-stream sedimentation and other depuration processes (Figure 5-17). Water quality monitoring results showed the stream was not polluted (Chapter 4). The low population density, the small scale of productive activities, and the efforts that DCC and the community undertook to counteract anthropogenic impacts over water sources, together with the high dilution and oxygenation capacity of the stream, rapidly buffered the pollution generated. Instead, the microcatchment was a provider of environmental services, including clean water for multiple uses, especially for human consumption, not only for the microcatchment population but also for downstream users.

Livestock farming generates risk factors for diarrhoea prevalence

Concerning TTC levels, based on loads from the literature and scale of pollution sources from primary data, the greatest contributions were cattle farms, but the dilution capacity in the stream and natural decay reduced the concentration of the organisms (Figure 5-18). Data from the water quality monitoring (Chapter 4) showed TTC concentration at the outlet was slightly above the limits for fresh water with low pollution (Chapman *et al.*, 1996). Therefore, livestock had less impact than expected on microbial water quality. However, removal of riparian vegetation in the livestock farming zone, where cattle had direct access still represented a risk and an opportunity for improvement. However, the restoration of riparian areas should be promoted along with mechanisms such as PES, as farmers must have incentives to invest in reducing the environmental impact of their economic activities, especially when benefits are more likely to be perceived downstream (Chará and Murgueitio, 2005; Pagiola *et al.*, 2005; Winter *et al.*, 2011).

Interventions by DCC have a positive impact on different dimensions of farmers wellbeing which are reflected at the microcatchment scale

A number of proven strategies available for implementation at different model sectors (preventive and corrective) to reduce the impact of anthropogenic activities and synergistically increase catchment health and human health and wellbeing were identified. These strategies include renovation of coffee plantations, silvopastoral systems, headwaters protection, restoration of riparian areas, ecological coffee processing, biodigesters, improved water and sanitation, and household water treatment. However, their implementation require the investment of different actors and proper transference to landowners and communities (Pagiola *et al.*, 2005; Clasen *et al.*, 2007; Kay *et al.*, 2007; Keirle and Hayes, 2007; Winter *et al.*, 2011). The management sector results showed DCC was almost the only institution investing in the microcatchment and other relevant actors had no presence in the area to fulfil their mandates (Figure 5-20).

Summarizing, in the system representation achieved, the profitability of economic activities was the driving force that influenced the decisions on land use, which alternated between livestock and coffee farming, with limitations posed by topography and soil fertility. Land uses determined the scale of economic activities that were associated with different levels of pollution, represented by TSS, BOD and TTC. TSS and BOD were considered indicators of stream health, while TTC was associated to human health for being a risk factor for the selected indicator, diarrhoeal disease. On the other hand, land use and therefore the scale of economic activities, in turn determined the number of jobs available and influenced migration and hence population dynamics. Population dynamics was also linked to the stream health and human health sectors contributing to TSS, BOD and TTC loads, and determining the population susceptible to diarrhoea. Management strategies implemented influenced key variables at different sectors in the model that could contribute with improvements on catchment health and human health and wellbeing.

The achieved model representation combined various aspects that have been identified as important for integration under the IWRM paradigm (GWP-TAC, 2000; Jonch-Clausen and Fugl, 2001) including: i) water and land; ii) natural system and human system; and iii) quantity and quality. The model considered distal and proximal factors as recommended by authors in health – environment related fields (Corvalán *et al.*, 1999; Ezzati *et al.*, 2005; Batterman *et al.*, 2009; Myers and Patz, 2009; Confalonieri and Schuster-Wallace, 2011). SD allowed visualizing the complex interplay of external factors that interacted with local conditions to generate outcomes in the study area. External dynamics such as free trade, climate variability, and revaluation policy interacted with land tenure patterns, communal infrastructure and natural resource availability, generating or buffering threats, making the population resilient or vulnerable to different system outcomes.

The analysis also involved aspects of environmental health, human health and social determinants of health as proposed by the EcoHealth approach (Forget and Lebel, 2001; Charron, 2012). Furthermore, the model used a microcatchment as the analysis unit as promoted by the integration between IWRM-EcoHealth (Parkes *et al.*, 2010; Bunch *et al.*, 2011). The model increased understanding of human health, using diarrhoeal disease as indicator by deeply characterizing the environmental and social context in which it occurred. This allowed identifying the importance of more preventive interventions such as increase improved sanitation that contributes to keep ecosystem resilience and the provision of various ecosystem services essential for human health and wellbeing (Walker, 1997; Postel and Thompson, 2005; Parkes *et al*., 2010; Bunch *et al*., 2011).

The model also helped to understand the linkages between livelihoods and natural resources management (Parkes *et al.*, 2010; Bunch *et al.*, 2011). It showed that if livelihoods are not profitable, the investment capacity of families to improve productivity, minimize the environmental impact of their productive activities, and invest in their homes and families is dramatically restricted. These limitations extend to the ability of investment from farmers unions that obtain resources directly or indirectly from farmers' contributions.

The model developed is a holistic, participatory, descriptive model, informed by the IWRM-EcoHealth framework by Parkes *et al.* (2010). The model as well as including multiple dimensions and catchments as the analysis unit, used SD to introduce systems thinking in a more tangible way, something these authors acknowledged were not clear in their proposal.

Model development involved some of the principles on which EcoHealth is based (Charron, 2012), and by extension IWRM-EcoHealth: systems thinking, transdisciplinarity, community participation; sustainability; social equity; knowledge in action. The process contributed to: (i) understand system operation, capturing its complexity; (ii) integrate dimensions; (iii) using the microcatchment as the analysis unit; (iv) integrate knowledge from multiple disciplines; (v) integrate knowledge and perspectives from different stakeholders; (vi) integrate proximal and distal causes on analysing system outcomes; and (vii) visualize interventions to influence system behaviour. This is believed the first explicit application of SD to IWRM-EcoHealth.

The results allow to better understand the numerous health and wellbeing challenges arising from environmental change and socioeconomic pressures in rural contexts of the developing world. Such improved understanding could be the basis to address the most relevant risks, estimate their impacts and help policy and decision makers to target resources. The results support the argument for the need of multi-sectoral and multilevel strategies as suggested by Jayasinghe (2011), and the opportunities for interventions that synergistically address human health and environmental management as promoted within the IWRM-EcoHealth approach by Parkes *et al.* (2010) and Bunch *et al.* (2011). The improved system understanding achieved from this systemic perspective reinforce the necessity identified in Chapter 4 to address needs and inequalities in rural areas through policies that aim to:

- Address the social determinants of health, prioritizing: access to education, health care (population sector), and land tenure (economic sector).
- Continue supporting the extension service to coffee farmers and strengthening extension services to livestock farmers, boosting strategies like silvopastoral systems (management sector and economic sector)
- Implement PES schemes as incentives to farmers for the adoption of more environmentally friendly practices, as compensations for the provision of environmental services (management sector, land use sector).
- Adopt multi-barrier and catchment management approaches to address drinking water quality (management sector, stream health sector, and human health sector).
- Increase the emphasis on sanitation coverage, protection of water sources, and household water treatment for the small fraction of water used for drinking and cooking (management sector, stream health sector, and human health sector).

5.5 Conclusions

In this chapter, SD was used to produce a semi-quantitative model that represents the relations between economic, social, environmental, technical, institutional and health and wellbeing factors at the catchment scale, using the conceptual framework and principles of IWRM-EcoHealth (Objective 3).

The modelling methodology and the Stella software, offered a common language that allowed integrating information from different dimensions to achieve comprehensive understanding of the system under analysis. The process facilitated: structuring the system, understand its functioning, identify key factors, distal and proximal, and analyse their behaviour. The process helped to organize thinking of stakeholders from different sectors, incorporate multiple perspectives, and disciplines. All these aspects are merits of participatory modelling processes recognized by authors in the SD field such as Vennix (1999), Van den Belt (2004) and Mirchi *et al.* (2012).

Even though the research was highly descriptive, there are few studies in Colombia addressing environmental and human health issues from a socio-ecological perspective, under the catchment approach, or devoted to rural areas. The modelling process provided stakeholders information that can serve to identify actions at various levels, including those to impact on demographics, agriculture, and infrastructure, which were causes of inequalities. In addition, it provides a baseline to monitor changes in the socioeconomic and environmental factors over catchment and human health and wellbeing of this population.

This process helped DCC to test hypotheses about system functioning, to find explanations for its behaviour, and identify strategic interventions (e.g. “ideas to explore” that guided the process described in Section 5.4). The process provided DCC with a conceptual tool and a baseline on key indicators and system configuration that could help them to reflect and discuss with other institutional stakeholders and communities, how the processes in the complex system of the microcatchment occur, and identify actions with the greatest potential for making the system to operate within desirable characteristics, maximizing positive impacts to the environment and the local communities. These are important outcomes on processes in EcoHealth, as highlighted by Forget and Lebel (2001), Wilcox (2001) and Charron (2012). The integration of previously fragmented knowledge and the generation of knowledge that was not available before, are considered by Carr *et al*. (2012) to be intermediary outcomes of participatory processes in water management, which would have potential to achieve future resource management outcomes. DCC is a pilot case that if successful, could be adopted nationwide by the NFC, benefiting 560,000 coffee farmers’ families.

5.5.1 Limitations

The integration of factors across dimensions posed the challenge of gathering information from multiple and sparse data sets and dealing with knowledge gaps (Batterman *et al.*, 2009). In this case, several information was not available at the microcatchment scale, lack of time series, or was collected over time with different methodologies. Therefore, the information available was mainly point data for the year 2013, supplied by DCC, CVC or collected by this research. In addition, gaps on variables and the relationships between them linked in the model structure also existed. Information gaps were addressed reviewing the literature and making several assumptions and estimates, but this prevented greater progress on model quantification.

Through the human health sector, annual cases of diarrhoea associated with quality of water sources, water supply systems and vulnerable populations were estimated. These were crude estimates and only provided a general idea of diarrhoea prevalence associated with pathogen bacterial contamination due to the water ingestion pathway. Although, water ingestion was presumably the most important pathway in *Calabazas* due to the high coverage of improved sanitation and the perception of a general adequate hygiene, there are several transmission routes of diarrhoea. In addition, diarrhoea is caused by a variety of pathogens, not only bacteria. Further exploration on which pathogens were present in the stream, their transport and survival mechanisms in soil and water would contribute to refine model assumptions and estimates.

When linking environmental health and human health, there are demographic, social, and landscape transformations occurring at regional scales over long time periods, that interact with changes in pathogen dynamics that occur on smaller spatial and temporal scales (Wilcox and Colwell, 2005). The time scales relevant to the phenomena that sought to be integrated represented a challenge. For example, the time scale of the population, economic and land use sectors was annual, whereas for diarrhoeal disease a daily scale should be more appropriate, since it depends on a daily infective dose. By embedding elements from QMRA, it was possible to obtain a number of annual cases of diarrhoea, but there are doubts about the potential of this approach on a fully-quantitative model performing simulations. Additionally, the model did not capture the seasonality of phenomena such as water pollution, and diarrhoea prevalence. According to Ford (2009), when the time scales of different sectors of a model diverge, it is better to have different models for different scales and make results of one model feed the other models.

Another limitation was that the model did not capture properly upstream - downstream relationships due to its uniform spatial scale. However, advances in SD achieved when coupling GIS allow adding spatial capabilities to the temporal abilities of SD (Ahmad and Simonovic, 2004; Simonovic, 2009). This could be an additional alternative for model refinement.

Chapter 6. General discussion and conclusions

6.1 Recapitulation of aims

The aim of this research was to contribute to the field of IWRM-EcoHealth to increase the understanding on the linkages between social and environmental determinants of human health and wellbeing and natural resources management at the catchment level, testing participatory approaches to System Dynamics as a methodology that helps to elucidate the connections between factors from different dimensions at different scales, involving multiple perspectives, disciplines, and integrating data collection and analysis strategies. To this end, the research comprised three main objectives:

- To understand stakeholders´ perceptions on the micro and macro factors affecting catchment health and human health and wellbeing

- To analyse the behaviour of socioeconomic and environmental factors related to catchment health and human health and wellbeing

- To develop a participatory systems model that integrates socioeconomic and environmental factors related to catchment health and human health and wellbeing in Andean rural microcatchments

The investigation was addressed under the case study research tradition, using qualitative and quantitative methods, and data were analysed using methodological triangulation and synthesis with systems thinking tools. The methodology and results for each of the objectives were described in Chapters 3 to 5, each chapter dealing with one of the proposed objectives.

6.2 Summary of results

The research results can be divided into: i) Stakeholders' perceptions on catchment health and human health and wellbeing; ii) Behaviour of socioeconomic and environmental factors related to catchment health and human health and wellbeing; and iii) Participatory systems model. The most significant findings are summarized as follows:

6.2.1 *Stakeholders' perceptions on catchment health and human health and wellbeing*

Stakeholders' perceptions on catchment health and human health and wellbeing were elicited from institutional and community stakeholders and those perceptions were used to identify factors, connections and develop a Causal Loop Diagram (CLD).

The perception of a healthy catchment by the institutional stakeholders was a catchment where coffee growing was competitive, cultivation practices and coffee processing were developed under an ecological approach, and soil, water and biodiversity were protected. Farmers were compensated for natural resource protection through Payment for Environmental Services (PES). Food security was guaranteed for families, and people were educated on care for nature. Coffee growing families were empowered and led sustainable development. In contrast, despite the fact, DCC was working for some time with the catchment approach and had provided training to farmers on IWRM, farmers were unclear about the concept and associated catchments to the place where they obtain water for consumption, and thus the most important attribute was water free of pollutants.

Although EcoHealth was new to DCC, they recognized linkages between healthy environment and healthy people, and saw connections between the environment, social determinants of health and human health and wellbeing, that were reflected in their programs, with interventions that integrated elements from the economic (profitability of coffee production), social (empowered communities leading the development of the catchment), environmental (protection of water sources and biodiversity), and human health and wellbeing dimensions (food security, sanitation, income), having the catchment as the managerial unit.

Stakeholders' mental models were synthesized on a CLD, representing the system under study and its behaviour (Figure 3-8). The diagram suggested farmers´ income was a central factor. This income depended on the profitability of coffee production and conditioned that both coffee growers and the NFC through the FoNC had resources to invest in different aspects related to environment, health and wellbeing (e.g. education, health, housing, sanitation, water, coffee renovation, fertilization, by-product management). However, profitability depended on internal (e.g. yield, area) and external factors (e.g. international coffee prices, national exchange rate policy). These perceptions were in line with the IWRM-EcoHealth perspective that sees human health broadly, encompassing social determinants of health and wellbeing, looking at the relations between health and water: "beyond the traditional focus on drinking water supply, sanitation, and contaminants to include livelihoods, employment, food and services provision, and catchments as contexts to address overlapping goals across environmental and health disciplines" (Bunch *et al.*, 2011). The CLD provided the foundations to start the process of developing a participatory model to link environmental health and human health in the studied microcatchment, and informed on the data that should be collected from primary and secondary sources.

6.2.2 Behaviour of socioeconomic and environmental factors related to catchment health and human health and wellbeing

The behaviour of socioeconomic and environmental factors related to catchment health and human health and wellbeing in *Calabazas* was analysed considering elements of the IWRM-EcoHealth conceptual framework, and the social determinants of health, built-in the premises of IWRM-EcoHealth. These approaches address human health and wellbeing, studying factors that are considered distal on the disease causal chain (Ezzati *et al.*, 2005; Eisenberg *et al.*, 2007; Ferrer *et al.*, 2008; Marmot *et al.*, 2008; Parkes *et al.*, 2010; Bunch *et al.*, 2011; Tiberghien *et al.*, 2011; Gentry-Shields and Bartram, 2013), and emphasizing the social and economic aspects that contribute to unequal health and wellbeing (Nagata *et al.*, 2011). For the purpose of this research, health outcomes were focused on diarrhoeal prevalence and the distal factors considered were education, employment, livelihoods, roads, health care, stream health, and sanitation. Proximal factors were focused on drinking water quality.

The results showed the behaviour of the social determinants of health such as roads, and access to education, and health care was poor or non-existent in real terms. In addition, the small size of the farms did not allow secure income and fair livelihoods. All these factors contribute to poverty, inequality, social unrest, and to worsen emigration (Marmot *et al.*, 2008; Malik, 2013). Emigration was expressed in the demographic pattern, where the proportion of the working age population was low and the elderly high. Furthermore, the female population was low compared to men, due to few income generating opportunities for them. As expected, the coverage of access to improved water sources was lower than the coverage in rural areas of Colombia and Latin America. However, protective effects on health such as water quantity and reliability were present to mitigate health and wellbeing losses and threats in relation to this aspect. Surprisingly, the coverage of access to improved sanitation was well above the national coverage and even above the urban coverage. This was result of both investment of families, and programs led by governmental and nongovernmental entities.

Stream water quality showed some deterioration in relation to land use from upstream to downstream in conductivity and Thermotolerant Coliforms (TTC). This decline had statistical significance for the dry season, showing differences in the coffee zone compared to the livestock zone. Despite a small decline, the parameters remained at levels that characterize unpolluted water bodies. The general good water quality suggests that strategies promoted by the Departmental Coffee Committee (DCC) to encourage the adoption of ecological coffee processing and secondary domestic wastewater treatment were working. Additionally, the stream had high dilution and self-purification capacity. The stream water survey yielded information about water quality, which were not available prior to this research. The stream was a healthy source, in line with community perceptions but in contraposition to the institutional beliefs expressed at the beginning of the process, and stated on several reports from institutions like the local government. These results, although not generalizable, challenge the general assumption that Andean microcatchments are polluted from the upper part due to anthropogenic impacts (Vidal *et al.*, 2009; IDEAM, 2010a).

In relation to drinking water quality, community organizations struggled to keep systems operating with resource constraints and lack of external support, mainly from the municipal administration. Still, due to their efforts, the water quality supplied by collective systems had relatively low levels of microbial contamination (< 35 CFU/100 ml). Furthermore, the high coverage of improved sanitation, contributed to have a microcatchment with low microbial pollution, for which levels at individual water systems were not substantially higher either (< 50 CFU/100 ml). Water in sufficient quantity, reliable supply and low proportions of storage at homes contributed to the low levels of microbial contamination. However, sporadic higher TTC levels were observed (~2000 CFU/100 ml), stressing the importance to continue working on source protection, and the need for a multi-barrier approach to mitigate the potential health impacts of these microbial peaks.

6.2.3 Participatory systems model

A participatory systems model was developed as a practical application of the IWRM-EcoHealth framework by Parkes *et al.* (2010). The model integrates social, environmental, and health and wellbeing dimensions using catchments as settings to address overlapping environmental and human health and wellbeing goals in the studied microcatchment. The process helped to understand the behaviour of the system under study. The profitability of economic activities was the driving force that influenced the decisions on land use, which alternated between livestock and coffee farming, with limitations posed by topography and soil fertility. Land uses determined the scale of economic activities that were associated with different levels of pollution, represented by Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD) and TTC. TSS and BOD were indicators of stream health, while TTC were associated also to human health for being a risk factor for the selected indicator, diarrhoeal disease. On the other hand, land use and therefore the scale of economic activities, in turn determined the number of jobs available and influenced migration and hence population dynamics. Population dynamics was also linked to the stream health and human health sectors contributing to TSS, BOD and TTC loads, and determining the population susceptible to diarrhoea. Management strategies influenced key variables at different sectors in the model that could contribute with improvements on catchment health and human health and wellbeing.

The model captured the linkages between livelihoods and natural resources management. It showed that if productive activities are not profitable, the investment capacity of families to improve productivity (renovate coffee plantations, increase herd size), make their economic activities more environmentally friendly (ecological coffee processing, silvopastoral systems), and better able to invest in their homes (improved water and sanitation) and families (education and health) was severely limited. These limitations extended to the ability of investment from institutions that work with resources from farmers´ contributions as a result of selling their products.

6.3 Contributions to theory

The process helped to organize thinking of stakeholders from different sectors that rarely interact. The methodology enabled incorporating multiple perspectives, disciplines, proximal and distal factors to better understand the myriad of health and wellbeing challenges arising from environmental change and socioeconomic pressures. This research makes contributions to theory in the following aspects: (i) implementation of the IWRM approach, (ii) empirical assessment of the premises of the IWRM-EcoHealth integration; and (iii) Using System Dynamics (SD) as a tool for the emerging field of IWRM-EcoHealth.

6.3.1 IWRM implementation

The description of the IWRM implementation process by DCC offered general guidance on how to use catchments as managerial units: (i) gain support from the general direction, (ii) establish a Geographical Information System (GIS) that operates with hydrological boundaries, but also with traditional (geopolitical) boundaries to facilitate interagency work; (iii) characterize microcatchments holistically but in relation to their particular areas of interest; (iv) redefine administrative units; v) assign staff and functions, and vi) implement pilot projects to evaluate and adjust the approach. This experience provides empirical evidence on how to implement IWRM, contributing to overcoming one of the criticisms of this approach, which is the lack of clear guidance on implementation as stated by Biswas (2004), Jeffrey and Gearey (2006) and Medema *et al.* (2008).

The experience showed there were people in DCC studying and reflecting conscientiously on the implications, opportunities and challenges to implementing IWRM, contrary to the lack of previous comprehensive analysis that has been suggested as a fault of IWRM implementation (Biswas, 2004). Although different definitions and conceptualizations of IWRM are considered an obstacle to implementation (Biswas, 2004; Biswas, 2008), DCC adopted IWRM from their perspective, looking at key elements in accordance with its mission and the environment in which they operate, in line with considerations of IWRM as a complex adaptive process, that is context-specific (Saravanan *et al.*, 2009).

DCC were flexible and used catchment boundaries in a pragmatic way, the catchment was the first choice to undertake any intervention. However, if there was not support, they were able to use the traditional approach of geopolitical units. This experience is consistent with the arguments for pragmatic approaches (Saravanan *et al.*, 2009), or flexible approaches where the catchment is an alternative with many possibilities, not an imposition (Johnson *et al*., 2001), rather a policy choice (Cohen and Davidson, 2011). These ideas contribute to fill a gap on institutional arrangements, managerial strategies and institutional capacities required to operationalize IWRM (Jeffrey and Gearey, 2006; Medema *et al*., 2008).

Despite progress and positive attitudes in DCC towards testing ideas, significant challenges were recognized as lack of resources to monitor the impact of interventions over the behaviour of multidimensional indicators at the catchment scale. This limits the possibilities to provide empirical data to evaluate the strategy, which is a general criticism on implementation studies on IWRM research, and exemplifies the difficulty to convincingly show the merits of the approach (Biswas, 2004; Jeffrey and Gearey, 2006; Medema *et al.*, 2008). To overcome this constraint, action-research could be a valuable strategy. Using action - research, development institutions can fund interventions and the researchers can provide resources to monitor the impacts of these, document, and contribute to theory. However, this poses other challenges, including finding organizations open to social learning, but even more, “synchronizing” the schedules of research and development, which usually occur at different speeds.

6.3.2 Empirical evaluation of the IWRM-EcoHealth premises

This research was a practical application of the premises from the IWRM-EcoHealth approach which aims to increase understanding of the linkages between social and environmental concerns with the determinants of health, using catchments as the spatial unit to organize knowledge for management of both human health and natural resources (Parkes *et al.*, 2010; Bunch *et al.*, 2011).

Evidence was presented on the situation of a rural community in a microcatchment in relation to: socioeconomic determinants of health, land use, resource availability, concentrations of bacteria in-stream and drinking water sources, water and sanitation infrastructure, human behaviour, governance, and diarrhoea prevalence. This information spans sectors and scientific disciplines, key features to increase understanding of the factors that determine human health and wellbeing (Myers and Patz, 2009), and water related diseases (Batterman *et al*., 2009). The results help to better understand the water - health nexus, distal and proximal causes of health, and social and environmental determinants of health at the catchment scale. This holistic understanding is essential to improve decision making processes for institutions trying to address the multidimensional needs of rural communities in the developing world.

6.3.3 Use of SD as a tool for the emerging field of IWRM-EcoHealth

Calabazas microcatchment was a complex adaptive system (CAS) that posed several multidimensional challenges. Several authors (Costanza and Ruth, 1998; Carpenter *et al.*, 2001; Holling, 2001; Anderies *et al.*, 2004; Folke, 2006; Young *et al.*, 2006; Pahl-Wostl, 2007a; Pahl-Wostl, 2007b; Ostrom, 2009) have suggested the challenges from CAS are better addressed using elements from perspectives such as adaptive management, resilience and adaptive capacity. CAS have common features with complex systems which behaviour can be understood by SD, a tool from the systems thinking paradigm (Forrester, 1961; 1987; Sterman, 2000). CAS and systems thinking inform the IWRM-EcoHealth perspective (Parkes *et al.*, 2010; Bunch *et al.*, 2011).

The model developed in this research is a holistic, participatory, descriptive model, informed by the IWRM-EcoHealth framework by Parkes *et al.* (2010). The process as well as including multiple dimensions and the catchments as analysis unit, used SD to introduce systems thinking in a more tangible way, something these authors acknowledged were not very clear in their proposal. SD was applied in this case to the IWRM-EcoHealth field, to provide a practical framework and tools to increase understanding on environmental and human health and wellbeing connections at the microcatchment scale.

Model development involved some of the principles in which the EcoHealth approach is based, and by extension IWRM-EcoHealth: systems thinking, transdisciplinarity, community participation; sustainability; social equity; knowledge in action. The modelling process contributed to: (i) understand system operation, capturing its complexity; (ii) integrate dimensions; (iii) using the microcatchment as the analysis unit; (iv) integrate knowledge from multiple disciplines; (v) integrate knowledge and perspectives from different stakeholders; (vi) integrate proximal and distal causes on analysing system´s outcomes; and (vii) visualize interventions to influence system behaviour. This is believed the first explicit application of SD to IWRM-EcoHealth.

Understanding system behaviour, capturing its complexity

The modelling process achieved a characterization of the relationships between the state of natural resources and human health and wellbeing through a systemic approach. The process served two purposes that have been identified as useful to be addressed through IWRM-EcoHealth: (i) understanding of sustainable livelihoods in agricultural economies that depend on water, and (ii) studying water-related diseases (Bunch *et al.*, 2011). In the first case, farmers´ livelihoods, their dynamics, and the factors that prevent these livelihoods provide an adequate quality of life were identified, linked to factors at different scales, from international prices to the land tenure structure in *Calabazas*. In the second case, water-related diseases were addressed from their distal causes (e.g. land use) to their health outcomes (diarrhoea prevalence).

The process made explicit the characteristics of complex systems that are difficult to understand by the human mind through traditional methods of discussion and debate as explained by Forrester (1987). For example, the lack of direct relationship between health outcomes (diarrhoea prevalence) and social (poverty) and environmental pressures (Andean forest loss) was an example of non-linearity, complex feedback loops, and time lags in the interactions of the relationships between different system components. Provision of good water quality in the stream despite the significant loss of the original forest and “rancherization” is an example of resilience. On the other hand, community efforts to keep water systems operating despite government neglect, the migration of family members to earn income outside the microcatchment; and DCC's efforts to find new funding sources for farmers on the challenging economic environment of the coffee business, are all examples of adaptive capacity. This complex network of interactions is characteristic of complex systems, whose understanding is better achieved through systemic (Costanza *et al.*, 1993; Sterman, 1994) or adaptive management approaches (Carpenter *et al.*, 2001; Bunch, 2003; Pahl-Wostl, 2007b; Medema *et al.*, 2008).

The approach taken in this process fits better the proposal by Vennix (1999), rather than those by Forrester (1987) and Sterman (2000), in the sense that the problems may initially be poorly defined, and SD facilitates better problem definition and analysis (Costanza and Ruth, 1998; Vennix, 1999; Stave, 2002; Van den Belt, 2004).

Integration of dimensions

In the achieved model representation, human health and wellbeing emerged as a result of the complex interactions of the subsystems: population, economic, land use, management, stream health, and human health. The model combined various aspects that have been identified as important for integration under the IWRM paradigm including (GWP-TAC, 2000; Jonch-Clausen and Fugl, 2001): (i) water (stream health sector) and land (land use sector); (ii) natural system (stream health and land use sectors) and human system (economic, population, human health and management sectors); and (iii) quantity and quality (dilution capacity and pollution loads). The model also integrated aspects of environmental health (stream health and land use sectors), human health (diarrhoea cases) and social determinants of health (employment, education, access to health care and income) in the context of a Socio-ecological system (SES), as proposed in EcoHealth (Forget and Lebel, 2001; Charron, 2012). Furthermore, the model used the microcatchment as the analysis unit as promoted in the IWRM-EcoHealth integration (Parkes *et al.*, 2010; Bunch *et al.*, 2011).

Using the microcatchment as the analysis unit of complex systems

Using the microcatchment as a unit of analysis allowed to connect aspects of land use, water quality, diarrhoea prevalence, and managerial strategies. The microcatchment provided a tangible context for analysing these different dimensions that could not be visualized with the same clarity when using other spatial unit for analysis. This approach allowed understanding proximal factors such as diarrhoea and drinking water quality, within the context of more distal factors such as land use, sanitation, and external factors such as international coffee price and revaluation. For instance, the sanitation interventions by DCC at the microcatchment level, being conducted at the village level, would have equivalent social impacts, but the environmental impact would differ, or at least it would not be possible to assess against water quality indicators in the main stream. A facilitator was that the total area of the microcatchment was within the same municipality (political boundary).

While to the people political boundaries were a clearer conception of territory compared to hydrological boundaries, once the microcatchment concept was explained, they identified themselves the relationships between land use, water quality and provision of environmental services to downstream users. Even though, the microcatchment perspective allows understanding those reciprocal relationships, it is not possible to state categorically that this unit of analysis is better than another, because a similar exercise was not conducted using a different unit of analysis to allow comparisons.

Integration of knowledge from multiple disciplines

It was possible to engage in model development with stakeholders from disciplines and expertise on fields such as agronomy, economics, sanitary, agricultural and forestry engineering, veterinary medicine, business administration, biology, epidemiology, microbiology, water quality modelling and statistics. Thirty-three stakeholders from nine institutions participated through different strategies and SD facilitated transdisciplinary research, based on a participatory methodology and a common language.

The language used for the modelling process, provided by the Stella software, was understood and embraced almost immediately by the variety of stakeholders. The language and the software made easier facilitation. Facilitation is considered a desirable characteristic of good participatory processes in WRM (Carr *et al.*, 2012). This common language that favours collective construction and communication, is a feature of SD that were experienced during model formulation, which has been highlighted by authors like Sterman (2000), Hjorth and Bagheri (2006), and Winz *et al.* (2009), as an important quality when applied to different fields, not yet to IWRM-EcoHealth. This was a key feature for the successful integration of sectors and actors, allowing transdisciplinarity, that opposes knowledge fragmentation, considered an obstacle to IWRM implementation (Biswas, 2004) and a core principle of IWRM-EcoHealth (Parkes *et al.*, 2010).

Integration of knowledge and perspectives from different stakeholders

In this modelling process stakeholders´ participation occurred from the outset, from problem definition, to building the model structure, making progress on quantification and providing feedback. The process involved the contributions from institutional stakeholders and the community. Institutional stakeholders participated in focus groups for model building, and they were interviewed in individual sessions. The community views were integrated by systematizing their perceptions on model aspects, captured through a household survey with open questions. What remains unknown is whether stakeholders with low education level, as *Calabazas* inhabitants, could participate effectively and in equitable conditions in a modelling process with the computer program, in groups made of institutional and community members. According to Saravanan *et al.* (2009), effective participation is in many cases, an unresolved issue in IWRM implementation.

Integration of local concerns, and proximal and distal causes on analysing system outcomes

After learning about the community perceptions through the household survey, sectors initially ignored in the proposal built only from the institutional perspective were included in the model (livestock and commercial forest sectors). Incorporation of these local concerns in the system structure is an important aspect in line with the sustainability principle in EcoHealth (Forget and Lebel, 2001; Wilcox, 2001; Charron, 2012). The model also took into account the conditions of the community which demonstrate how government neglect has led to unfavourable quality of life, such as precarious jobs and access to services. This is the type of unequal circumstances that threaten human health and wellbeing, the EcoHealth approach seeks to address as part of its social equity principle (Forget and Lebel, 2001; Charron, 2012).

The participatory model also addressed the external forces (e.g. international coffee prices, free trade) contributing to poverty, environmental degradation and reduced population wellbeing (Charron, 2012). SD allows to include "distal" factors, which are key variables that influence systems´ behaviour, capturing the property of endogeneity. Endogeneity helps discern the counterintuitive behaviour of complex systems, in which cause and effect are distant in time and external driving forces affect local problems (Forrester, 1961; 1987; Sterman, 2000; Richardson, 2011). This approach is opposite to that used in disciplines such as epidemiology, where causes are explored near the events to find explanations for the phenomena under study (Ezzati *et al.*, 2005; Batterman *et al.*, 2009), and which is considered insufficient to address the social and ecological dimensions of human health (Ansari *et al.*, 2003; Eisenberg *et al.*, 2007; Eisenberg *et al.*, 2012).

Visualization of interventions to influence system behaviour

The modelling process evidenced the limited availability of jobs, the low profitability of livelihoods, migration and population aging, and the lack of government investment in this rural area. The increased understanding of problematic system behaviour enabled visualizing managerial strategies that could lead to better system performance (Forrester, 1961; 1987; Sterman, 2000; Richardson, 2011). The process also validated the importance of interventions undertaken by DCC and the community, such as protection of water supply sources, sanitation, renovation of coffee plantations and ecological coffee processing. It also highlighted the need to intervene in neglected areas such as: promotion of agroforestry systems, restoration of riparian corridors, Household Water Treatment (HWT), and Payment for Environmental Services (PES). Likewise, the need for structural interventions in land tenure, land use patterns, extension services for farmers, and effective access to education and health care services for the entire population.

The process helped to identify barriers to the implementation of policies such as PES. Despite being a theoretically sensitive strategy that was seriously considered by some stakeholders, PES was seen by others as difficult to realize, or with a likely evolution that may result in environmental benefits (acquisition of land in strategic areas), but would not provide social benefits (no an alternative source of farmers´ income).

The process contributed to identify strategies that can be applied at different subsystems or model sectors, with impact on improving human health (sanitation, treatment at point of use), make production practices more environmentally sound (silvopastoral systems) and maintain or improve ecosystems´ integrity (source protection and restoration of riparian strips). Some of these strategies are preventive and help preserve ecosystem services and build resilience of human and environmental health. These strategies emerged from a thorough analysis of the context, with stakeholder participation and therefore, may have high impact to improve system behaviour if implemented.

The process helped to recognize inadequate policies, such as centralized disinfection in rural water supply systems with few users. This is an example of responses to problems that fail or worse situations, when linear solutions proximate to causes are implemented in complex systems, which are policy-resistant.

The microcatchment-scale interventions by DCC, despite not being proposed directly based on the IWRM-EcoHealth approach, fit well with this proposal as they incorporate elements that look water beyond the traditional approach of quality, sanitation and pollutants, and add the dimensions of poverty reduction, improvement of social determinants of health, maintenance or (restoration) of ecosystems´ integrity, promotion of sustainable livelihoods, and equity to simultaneously promote human health and ecosystem resilience as proposed by Bunch *et al.* (2011).

6.4 Contributions to policy

Most of the issues that emerged in relation to the situation of the population in *Calabazas* have been part of the international community calls to improve living conditions in rural areas. Among them, the need to increase farmers' income by improving access to land, credit and extension services (Marmot *et al*., 2008), and the need for protection against the adverse effects of free trade agreements (Malik, 2013). Furthermore, there is growing recognition that increasing income alone does not solve the needs of rural populations, but that increased investment in pro-poor interventions such as roads, access to health, and education are required (Kanji *et al*., 2012; Malik, 2013). Particular emphasis has been made in one of the potentially more high-leverage policies, which is increase the education level of women (Malik, 2013).

The results support the prospect for implementing PES to incentive farmers adopting Best Management Practices (BMPs), as compensations to upstream communities as providers of environmental services (Pagiola *et al.*, 2005; Postel and Thompson, 2005). PES are considered a mechanism that could contribute to address synergistically challenges of rural poverty reduction, rural development and environmental protection (Postel and Thompson, 2005). The results highlight the importance to maintain the extension services provided to the coffee growers, and the need to strength and increase the coverage of extension services to livestock keepers, since many best management practices designed to reduce pollution require farm-scale interventions with associated costs, which demand integration of different sectors to cooperate (Kay *et al*., 2007).

The results also align to the view of multiple barriers to ensure the safety of drinking water, and approaches such as catchment protection, water safety plans, and water supply catchments. These approaches indicate that a protected catchment is the first barrier for obtaining safe drinking water quality with the benefit of low treatment costs (Lee and Schwab, 2005; Kay *et al.*, 2007; Keirle and Hayes, 2007; Confalonieri and Schuster-Wallace, 2011; Winter *et al.*, 2011; WHO, 2012a). This is important not only for cities in fast urbanization processes downstream, but also for poor communities upstream that manage water supply systems facing substantial constraints on all kinds of resources.

The information in this study contributes to the current debate about progress on target 7c of the Millennium Development Goals (MDGs) and the Post 2015 agenda on access to water on the need to revise the figures for access to safe water in Colombia, as is being done in other parts of the world to include the water quality dimension, and define the orientation of the water sector investments. Alternatively, to consider a differentiated approach for rural areas, adopting more flexible medium-term quality standards for systems without treatment, more attainable for community-managed organizations (Jensen *et al.*, 2004; Parker *et al.*, 2010), and catering for the multidimensional water needs of rural people (Van Koppen *et al.*, 2009).

Results suggest that increasing sanitation coverage, protection of sources, improving networks, and household water treatment for the small fraction of water used for drinking and cooking may be more sensible choices compared to centralized disinfection systems, in contexts such as the microcatchment, where microbial pollution levels are low and the local resources to maintain these facilities are limited. This study provides evidence that support consideration of sanitation as an important strategy to implement in rural communities, perhaps above communal water supply, to reduce the prevalence of diarrhoea (Esrey, 1996; Gentry-Shields and Bartram, 2013) and in general to achieve human health and wellbeing.

The findings support the consideration of alternative approaches for water provision in rural areas such as “supported and recognized” self-supply (Kumamaru *et al.*, 2011; Butterworth *et al.*, 2013; Moriarty *et al.*, 2013). This is an option that could help to increase access to safe water in scattered areas with difficult topography, abundant and relative good water quality. This supported and recognized self-supply will require the development and transfer of packages for the design, construction, Operation and Maintenance (O&M) of water supply systems for individual households, encompassing multiple uses of water.

The research contributed with evidence on the need to design municipal schemes to support communal water committees to increase their capacities to supply water. This support will help to ensure the reliability and quality of services over time, in cases were first time access has been already achieved (Moriarty *et al.*, 2013; Smits *et al.*, 2013).

6.5 Contributions to practice

The process helped DCC to test hypotheses about system functioning, to find explanations for its behaviour, and identify strategic interventions. This methodology goes beyond the procedure of the researcher proposing factors or indicators to stakeholders. In this case, the factors and the relations between them were elicited from the stakeholders´ knowledge and their direct experience operating in the system. The role of the researcher was to provide theoretical basis related to conceptual frameworks and tools, based on the systems thinking paradigm, to synthesize and integrate the stakeholders´ knowledge and views.

Stakeholders´ participation through the research allowed mutual learning. As knowledge was generated as part of the process, it was shared and discussed with institutional and community stakeholders. The primary information resulting from system characterization in relation to social determinants of health, stream and drinking water quality was shared with community leaders. Thus, the research provided these leaders with information they lacked and new techniques for collecting data to identify the status of their microcatchment holistically. These results endowed the community with qualitative and quantitative data, collected and analysed with academic rigour that validate their perception of their strengths and challenges. The results equipped leaders with information that help them to lobby the institutions responsible for implementing development programs. On the other hand, the communities offered opportunities for learning about resilience and adaptive capacity, and on the innovative solutions and strategies, they developed for delivering services and manage their environment with their limited resources and according to their context.

Besides learning about system´s structure and behaviour from the institutional stakeholders, progress in model formulation was shared with those involved in model construction. The semi-quantitative model provides a set of multidimensional indicators, which are measurable, and linked with dimensional coherence (i.e. units between factors that are related coincide). Furthermore, a baseline for the behaviour of most factors is provided for the year 2013. The model informs about data that is important to start monitoring and the need to investigate relationships that are poorly known in the system at this particular time. This is considered an important result of qualitative modelling (Mirchi *et al.*, 2012) and a key outcome of participatory processes in EcoHealth (Charron, 2012). In addition, the integration of previously fragmented knowledge and the generation of knowledge that was not available before, are considered intermediary outcomes of participatory processes in water management, which would have potential to lead to resource management outcomes in the future (Carr *et al.*, 2012).

The process contributes to document the actions undertaken by DCC and refine the design and implementation of their initiatives aimed at coffee farmers´ wellbeing, using microcatchments as managerial units. The process provides DCC with a tool that could help them to reflect and discuss with other stakeholders about the complex system of this microcatchment, and identify the actions with the greatest potential for making this system to operate within desirable characteristics, maximizing positive impacts to the environment and the local communities.

The model could be a tool to enable the DCC to try cyclical learning processes to move towards adaptive management, helping them to design, implement, monitor, evaluate and review their managerial strategies. DCC is a pilot case for the National Federation of Coffee Growers (NFC) that if successful, could be adopted by other Departmental Coffee Committees in Colombia. The influence of the NFC extends to 3.3 million acres that comprise the Colombian coffee region, of which 914,000 are planted in coffee and where about 560,000 families derive their livelihoods (FNC, 2012). In addition, results from this study may be relevant to other unions in the country working for poor farmers, such as livestock, onion and potato farmers, which are not as organized as the NFC.

6.6 Limitations

Financial restrictions led the research to adopt a single case methodology. Therefore, results cannot be generalized. Nevertheless, the findings on drinking water quality and stream water quality are consistent with those from Roa-García and Brown (2009) in another small rural Andean microcatchment in Valle del Cauca (Colombia), and the findings on community management and external support concur with those from Smits *et al.* (2013). The results were shared and analysed with the community and there was consensus that the findings reflected the situation. Furthermore, the ongoing stakeholders´ participation from proposal formulation to the analysis of results, help to construct validity to the case. In-depth studies like this in other Andean microcatchments will contribute to increase the current low level of information on these strategic but highly intervened ecosystems in Colombia, where most of the population is concentrated.

The model sectors that emerged from the system representation achieved are relevant to the context of *Calabazas*. Each context has their own factors and dynamics that determine outcomes (Jayasinghe, 2011), and findings are context-specific as most case studies addressing sustainability (Schwenke *et al.*, 2003; Batterman *et al.*, 2009). Nevertheless, the methodological process developed could be replicated in other microcatchments, looking for holistic understanding of environmental health and human health and wellbeing, especially for DCC to refine their approach to IWRM.

When building the participatory model, factors related to the individual and farm scales identified by stakeholders were aggregated or removed to obtain a microcatchment-scale model. This is a limitation that should be considered if SD will be part of the toolkit for IWRM-EcoHealth, because diseases are associated not only with social and environmental factors but also to individual factors (e.g. vulnerability of individuals, behavioural practices, attitudes and personal values). However, in EcoHealth, the main interest is assessing health at community or sub-group level (Charron, 2012).

For logistical reasons the various institutional stakeholders could not be together at the same time and space, debating the model structure and system behaviour, as suggested by SD approaches such as Mediated Modelling (MM) (Van den Belt, 2004). However, this limitation was overcome by visiting stakeholders individually and incorporating their perceptions and knowledge. Another limitation was the failure to contact the forestry company staff to capture their views on the system, since there were no referencing routes leading to this stakeholder. Although, MM would have been the preferred alternative to allow interaction of stakeholders from different sectors (Van den Belt, 2004), the origin and evolution of the research led to a Group Model Building (GMB) (Vennix, 1999), where the “client” was DCC. This GMB process was subsequently “democratized” allowing inputs for a greater number of people from different institutions.

Institutional and community stakeholders were not at the same time exchanging perceptions and knowledge during model construction. Thus, different components of the research were tailored to allow participation of the two stakeholders´ groups. Institutional actors were involved in modelling and community actors in characterizing the system, collecting data, analysing results and discussing their implications. This decision was made due to identified barriers which surpass was a challenge that would exceed the time available within a PhD: while institutional stakeholders were professionals, most community stakeholders had incomplete primary education. Additionally, community stakeholders generally distrusted institutional stakeholders. Although in this case there was no co-production in the literal sense (Corburn, 2003; 2007), the difference in perceptions and knowledge between stakeholders´ groups found, reinforces the need to seek mechanisms to integrate these diverse perspectives, as both forms of knowledge are complementary (Corburn, 2003; Van den Belt, 2004; Corburn, 2007; Charron, 2012).

The study employed mixed methods (qualitative and quantitative): in-depth interviews, semi-structured interviews, household survey, water quality monitoring, and review of data archives, that were synthesized using SD. In this way, the research embraced the challenge of integrating data collection and analysis of multiple variables from different sectors and disciplines to increase system understanding (Ezzati *et al.*, 2005; Batterman *et al.*, 2009). However, this integration posed the challenge of using multiple and sparse datasets and dealing with knowledge gaps (Batterman *et al.*, 2009). This situation limited greater progress on model quantification. In addition, the relationships between key variables to understand the system dynamics were unknown, such as linkages among factors from the population, economic, stream health and human health sectors. The information gaps were addressed reviewing the literature and making several assumptions and estimates. This situation reflects the need to start collecting information periodically on relevant variables to enable future analysis of historical trends, and potentially progress on model quantification arriving at a working model that allow simulations, which is an important component of SD.

Due to the extreme complexity of diarrhoea - different pathogens and different routes of transmission associated with different spatial and temporal scales -, the model focused on addressing one route of transmission (ingestion of drinking water) associated with one type of pathogen (bacteria). For model refinement, new components could be added to the model to cover other routes of transmission and other pathogenic organisms such as viruses and protozoa. However, the estimates obtained provide information for management and suggest types of interventions and the impact these could achieve on the cases addressed. It also allowed analysing diarrhoea from the perspective of their distal and proximate causes.

Using SD as a tool for the analysis of catchment health and human health and wellbeing in the complex SES of a microcatchment was adequate to address implementation challenges identified in IWRM-EcoHealth regarding to issues of: jurisdiction, integration of disciplines, professional fields, multiple perspectives, biotic and abiotic aspects, livelihoods and communities as highlighted by Parkes *et al.* (2010) and Bunch *et al.* (2011). However, gaps remain in properly addressing the cross spatio-temporal scales posed by the studied phenomena. When linking environmental health and human health, there are transformations occurring at regional scales over long time periods that interact with changes in pathogen dynamics that occur on smaller spatial and temporal scales (Wilcox and Colwell, 2005). The time scales of the phenomena that sought to be integrated in the model represented a challenge, since SD did not appear to be well suited to address problems with incompatible time scales. Another limitation was that the model did not capture properly upstream - downstream relationships due to its uniform spatial scale. However, alternatives such as having different models for different time scales (Ford, 2009) and considering the spatialization of models through GIS tools (Ahmad and Simonovic, 2004; Simonovic, 2009) are available options that could contribute to overcome these limitations.

The model was mainly based on qualitative modelling tools used at different stages of the process (causal relationships between factors, CLD, and stocks and flows diagram). The stocks and flows diagram included key variables that were characterized by reference modes of behaviour, where there were historical information available. Progress on quantification arrived at the point in which the status of all parameters that comprised model structure were known at one point of time (2013). Nevertheless, the equations describing the dynamic change of the stocks in time and allowing simulations were not formulated. It was decided not to progress further in quantification, as there were many gaps in data availability on model variables and relationships between them, which could not be filled in the time available.

Although within SD, authors such as Forrester (1987) and Sterman (2000) consider simulation as the only way the modelling process and its results contribute to better system understanding and policy design, authors like Vennix (1999) believe qualitative models have merit in themselves and that success on Systems Dynamic Modelling (SDM) processes depends not only on simulation. Vennix (1999) points out cases of high complexity systems in which quantification decreased the relevance of the model to the stakeholders, or was biased. Mirchi *et al.* (2012) believe the potential of the SD qualitative tools has not been sufficiently exploited to address water resources problems. In addition, authors in EcoHealth believe that systems thinking and the use of diagrams representing systems´ complexity and help analyses are important results that contribute to problem understanding and identifying appropriate contextual solutions (Neudoerffer *et al.*, 2005; Waltner-Toews *et al.*, 2008).

6.7 Future work

Future work could address the limitations discussed in Section 6.6, including: use a multiple cases methodology, have stakeholders from different institutions and possibly from the communities debating at the same time and space on model structure, incorporate other routes of diarrhoea transmission and indicators for different pathogen groups, and progress further on quantification. However, progress on quantification will require as prerequisite to study factors and relations between them, which are currently poorly understood in Colombia. For instance, analyse historical data from different contexts to explore linkages between aspects that appeared relevant in the model including: (i) profitability of productive activities and land use change; (ii) profitability of economic activities and migration; (iii) climate variability and production of the main agricultural products; (iv) land use and water quality; (v) climate variability and water quality; (vi) climate variability and diarrhoeal disease. Study of these relations demand improvements on monitoring and surveillance efforts, especially at finer scales of the institutions involved and easier access for researchers to this information.

Further progress on quantification and simulation could use several models operating at different time scales to better represent the temporal scales relevant to the different model sectors and consider using GIS to improve spatial representation. Simulation could contribute to identify the features and thresholds in the system that must be maintained to continue providing environmental services and inform the required efforts to reduce the undesirable current situations expressed on gaps in access to education and health care, poor livelihoods, and access to land, which are structural causes of deprivation and inequalities in these communities.

Beyond further progress on quantification, the methodology could be applied to study other rural microcatchments to identify linkages and the behaviour of different social and environmental factors to inform the design of programs by different actors at different levels. In addition, evaluative studies could be carried out by working with institutions such as DCC, with a positive attitude towards social learning processes that can be a laboratory to obtain lessons on the interventions that are required in rural areas to improve environmental health and human health and wellbeing. Lessons from evaluative studies may be relevant to different farmer unions in Colombia and other developing countries.

Questions to develop innovations needed to identify solutions to the problems of the Colombian countryside and adapt them to its diversity, emerged from this exploratory study. Some questions are new and others old but have seen decades without being solved or even without genuine interest in addressing them. Other questions support the need to continue researching on topics that research groups in Colombia are currently investigating:

- What are the ecosystem services that Andean agroecosystems provide and what is the value of these services?
- How could schemes of Payment for Environmental Services be implemented?
- What is the impact of extensive livestock on Andean water bodies?
- How could extension services be improved for livestock farmers?
- How could the implementation of silvopastoral systems be accelerated?
- What is the effect of riparian strips over water quality and what managerial strategies could be designed and implemented to restore them?
- What are the pathogens present in Andean streams, which are their sources and what are the risks they pose to public health?
- How are the dynamics of transport and survival of pathogenic microorganisms in Andean microcatchments?
- What are the specific pathogens present in drinking water sources and what are their levels?

- What is the dilution and self-purification capacity of Andean streams?
- How are the costs of supplying drinking water from protected watersheds compared with the costs of supplying drinking water from degraded catchments?
- Is chlorination the most efficient and effective solution to improve drinking water quality in rural community-managed systems used for multiple purposes?
- How could external support services for community-managed water systems be designed and implemented?
- How could people using self-supply water systems be supported to improve their drinking water quality?
- What technological packages are appropriate for the design, construction, operation and maintenance of water supply systems for individual households, encompassing multiple uses of water?
- What strategies could be implemented to increase the adoption of household water treatment?

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Appendices

Appendix A General topics for semi-structured interviews

- Pressing problems regarding catchment status
- Pressing problems regarding people health
- Perceived constraints to address those problems
- Problems causes
- Problems consequences
- Initiatives being carried out concerning catchment health and human health
- Institutions or people involve in those initiatives
- Coordination between institutions
- Processes, outcomes and monitoring strategies
- Mechanisms for community participation
- Coordination and partnerships with other institutions
- Long-term support to beneficiaries
- Perceived opportunities and constraints to achieve the expected outcomes

Table A -1. First round semi-structured interviews with DCC staff

Date	Activity	Participants	Position
23/11/2011	Group interview	C1[27]	Director of extension programs (*Gatekeeper for the research*)
		C5	Sanitary Engineer
		C4	Economist
02/12/2011	Individual interview	C7	GIS manager
31/01/2012	Group interview	C1	Director of extension programs
		C4	Economist
		C6	Manager director Peace footprints project
		C3	Agricultural engineer
14/11/2012	Individual interview	C1	Director of extension programs (*Gatekeeper for the research*)
23/11/2012	Individual interview	C1	Director of extension programs (*Gatekeeper for the research*)

[27] C means that the stakeholder belongs to the Departmental Committee of Coffee Growers of Valle del Cauca, the number is to distinguish different people within the organization.

Appendix B Household Survey with *Calabazas* local community

A. Enumerator

1	Name ____________________________	2	Date ________________	3	Questionnaire number _________________
4	Settlement_________________________	5	Sector ___________________________	6	Household number ___________________

B. Supervisor

1	Date _____________________	2	Observations ____

C. Introduction

Good morning / Good afternoon, my name is _________________. I am a neighbour from ________________ and I am here today because we are undertaken a research with help from Universidad del Valle, about water in this region. I would like to make you some questions for this research. Participation is voluntary and the information that you provide to us will remain confidential. You could end the survey when you like and only answer the questions you like. Not Universidad del Valle neither the Coffee growers´ federation or any other institution would be able to know your individual answers to the questions. However, the results from all surveys will be processed and the aggregated results presented to the community to increase our knowledge with regards the status of our water supply systems and water sources. The survey will take around 30 minutes. Do you have any questions with regards to the research? Would you like to cooperate with the survey?

D. General Aspects

1 What is your name? ________________________	2 *Surveyed gender* Female ...1 Male ...2	3 What is the farm´s name? ________________________

4 How many people live in this household? ________	5 How many people living in this household are five years old or under? __________	6 How many people living in this household are over five years old? __________	7 Does the number of people living in this household increase during weekends? Yes ...1 No...2 How many additional people? ______	8 How long does your family have lived in this settlement? _________

E. Access and use of water

	Activities	What is the water source that you use for (*name activities from 1 to 7*)? (*Do not read the alternatives to the interviewed*)								
		Communal system	*Individual system*					*Other, which?*	*Not applicable*	*DK / DA*
			Protected spring	*Unprotected spring*	*Fetching*	*Rainwater*	*Bottle water*			
1	Drinking and cooking	...1	...2	...3	...4	...5	...6	...77	...88	...99
2	Hygiene	...1	...2	...3	...4	...5	...6	...77	...88	...99
3	Toilets	...1	...2	...3	...4	...5	...6	...77	...88	...99
4	Coffee processing	...1	...2	...3	...4	...5	...6	...77	...88	...99
5	Watering animals	...1	...2	...3	...4	...5	...6	...77	...88	...99
6	Cleaning of stables	...1	...2	...3	...4	...5	...6	...77	...88	...99
7	Irrigation	...1	...2	...3	...4	...5	...6	...77	...88	...99

8 How would you classify the quality of your water in dry season?

Very bad	...1
Bad	...2
Not bad not good	...3
Good	...4
Very good	...5

9 How would you classify the quality of your water in rainy season?

Very bad	...1
Bad	...2
Not bad not good	...3
Good	...4
Very good	...5

10 Do you use (*name answer 1*) for drinking and cooking through the year?

Yes	...1
No	...2
Other, which? ________________	...77
DK / DA	...99

(If any of the answers to questions 1-7 was 1- the house receives water from a communal system- continue with 11, otherwise go to Section F)

11 Who is the service provider?

Acuacalabazas	...1
Calabazas	...2
Acuamiravalle	...3
Acuafenicia	...4
Other, which? __________	...77
DK / DA	...99

12 Which is the frequency of service during dry season?
(Do not read the alternatives to the interviewed)

Three times a week	...1
Every day	...2
Other, which? ____________	...77
DK / DA	...99

13 How many hours do you receive the service during dry season?
(Do not read the alternatives to the interviewed)

1 - 3 hours	...1
4 – 7 hours	...2
8 – 11 hours	...3
12 - 23 hours	...4
24 hours	...5
DK / DA	...99

F. Sanitation aspects

1 HOW DO YOU DISPOSE HUMAN EXCRETA?
(Do not read the alternatives to the interviewed)

Communal sewer	...1
Individual wastewater treatment system	...2
Septic tank	...3
Pour flush latrine	...4
Natural drainage	...5
Water source	...6
Pit latrine with slab	...7
Pit latrine without slab	...8
Biodigester	...9
Compost	...10
Open field	...11
Other, which? ____________________	...77
Not applicable	...88
DK/DA	...99

2 HOW DO YOU DISPOSE PIGS´ EXCRETA?
(Do not read the alternatives to the interviewed)

Communal sewer	...1
Septic tank	...2
Pour flush latrine	...3
Natural drainage	...4
Water source	...5
Pit latrine with slab	...6
Pit latrine without slab	...7
Biodigester	...8
Compost	...9
Open field	...10
Dry cleaning	...11
Other, which? ____________________	...77
Not applicable	...88
DK/DA	...99

3 HOW DO YOU DISPOSE WATER FROM COFFEE PROCESSING?
(Do not read the alternatives to the interviewed)

Plot	...1
Water	...2
Natural drainage	...3
Communal sewer	...4
Septic tank	...5
Biodigester	...6
Other, which? ____________________	...77
Not applicable	...88
DK/DA	...99

4 HOW DO YOU DISPOSE SOLID WASTE FROM THE FOOD PREPARATION?
(Do not read the alternatives to the interviewed)

Water source	...1
Plot	...2
Burnt	...3
Buried	...4
Service provider	...5
Animal feed	...6
Compost	...7
Other, which? ____________________	...77
Not applicable	...88
DK / DA	...99

5 HOW DO YOU DISPOSE WASTE FROM POULTRY?
(Do not read the alternatives to the interviewed)

Water source	...1
Plot	...2
Burnt	...3
Buried	...4
Service provider	...5
Animal feed	...6
Compost	...7
Fertilizer	...8
Other, which? ____________________	...77
Not applicable	...88
DK / DA	...99

6 HOW DO YOU DISPOSE WASTE FROM COFFEE PROCESSING?
(Do not read the alternatives to the interviewed)

Water source	...1
Plot	...2
Burnt	...3
Buried	...4
Service provider	...5
Animal feed	...6
Compost	...7
Pit	...8
Other, which? ____________________	...77
Not applicable	...88
DK / DA	...99

G. Hygiene

1 Do you store your drinking water?

Yes	...1
No	...2
DK / DA	...99

(If the answer is yes, continue with 2, otherwise go to 5)

2 How do you store your drinking water?
(Do not read the alternatives to the interviewed)

Barrel(s)	...1
Tank(s)	...2
Bucket(s)	...3
Bottles	...4
Other, which? ________________	...77
DK / DA	...99

3 Does the container have lid?

Yes	...1
No	...2
DK / DA	...99

4 How the water is taken from the container?
(Do not read the alternatives to the interviewed)

Bucket	...1
Faucet	...2
Other, which? ____________________	...77
DK / DA	...99

5 Do you treat your drinking water in your house?

Yes	...1
No	...2
Other, which? ____________________	...77
DK / DA	...99

(If the answer is yes, continue with 6, otherwise go to section H)

6 How do you treat your drinking water?
(Do not read the alternatives to the interviewed)

Boiling	...1
Chlorination	...2
Filtration	...3
Sedimentation	...4
Other, which? __________________	...77
Not applicable	...88
DK / DA	...99

H. Health aspects

1 Why do you think a person gets diarrhoea?

____
____
____
____

2 How high do you think is the risk of contracting diarrhoea from drinking water to you or your family?

Very high	...1
High	...2
Not high not low	...3
Low	...4
Very low	...5

3 When you or any of your family members get diarrhoea, how serious do you think does it affect your or their health?

Very serious	...1
Serious	...2
Not serious, not trivial	...3
Trivial	...4
Very trivial	...5

4 Have you or any member of your family had diarrhoea in the last 2 weeks? *(Diarrhoea is determined as perceived by mother or caregiver as three or more loose or watery stools per day, or blood in the stool).*

Yes ...1 No ...2 *If the answer is yes, continue with 5 otherwise go to question 11*

	5 Family members who have diarrhoea in the last 15 days	6 What is the age of (name)?	7 Age units Years ...1 Months ...2	8 During the last diarrhoea episode, Does (name) take any beverage or medicine? (Do not read the alternatives to the interviewed) Liquid made from a special package ...1 Homemade beverage recommended by some authority ...2 Oral rehydration package ...3 Did not take beverage or medicines ...4 Other, which? ...77 DK / DA ...99	9 During the last diarrhoea episode, any help or treatment was sought for (name) out from the household? Yes ...1 No ...2 DK / DA ...99 (If the answer is No, go to 11)	10 Where help was seek for (name)? (Do not read the alternatives to the interviewed) Public clinic ...1 Public hospital ...2 Private health centre ...3 Friend or relative ...4 Drugstore ...5 Store ...6 Other, which? ...77 DK / DA ...99
1						
2						
3						

		11 During the past twelve months, any of the family members have experienced any of the following diseases or symptoms (name the diseases or symptoms) Yes ...1 No ...2 DK / DA ...99	12 How would rate the problem of (name the disease or symptom experienced)? Very serious ...1 Serious ...2 Not serious, not trivial ...3 Trivial ...4 Very trivial ...5	13 Was any help or treatment seek for (name the disease or symptom experienced) out from the house? Yes ...1 No ...2 Go to 15 DK/DA ...99	14 Where did you sought for help to treat (name the disease)? (Do not read the alternatives to the interviewed) Public clinic ...1 Public hospital ...2 Private health centre ...3 Friend or relative ...4 Drugstore ...5 Other, which? ...77 DK / DA ...99	15 Why did not sought for help (name the disease)? (Do not read the alternatives to the interviewed) Do not have money ...1 There was not a nearby place ...2 It was thought this could be treated at home ...3 Other, which? ...4
1	Severe diarrhoea					
2	Fever					
3	Vomit					
4	Respiratory infection					
5	Eye infection					
6	Skin infection					
7	Throat infection					

I. Perceptions on human and catchment health

1 WHAT IS FOR YOU A MICRO-CATCHMENT? ____________________ ____________________ *(If the interviewee does not know go to 4)*	**2** DO YOU KNOW IN WHAT MICRO-CATCHMENT YOUR FARM IS LOCATED? Yes, ...1 No ...2 DK / DA ...99 *(If the answer is yes, continue with 3, otherwise go to 4)*	**3** WHAT IS THE NAME? ____________________ ____________________ ____________________
4 CURRENTLY, DO YOU OR ANY OF YOUR FAMILY MEMBERS DEVELOP RECREATIONAL ACTIVITIES IN THE NEARBY STREAMS? Yes, ...1 No ...2 DK / DA ...99 *If the answer is yes, continue with 5, otherwise go to 7*	**5** WHAT KIND OF ACTIVITIES? *(Do not read the alternatives to the interviewed)* Swimming ...1 Walks ...2 Fishing ...3 Hunting ...4 Other, which? __________ ...77	**6** HOW OFTEN DO YOU DO THESE ACTIVITIES? *(Do not read the alternatives to the interviewed)* Once a week ...1 Once a month ...2 Twice a year ...3 Other, which? __________ ...77 DK / DA ...99
7 WHAT WOULD BE FOR YOU A HEALTHY MICRO-CATCHMENT? ____________________ ____________________ *(If the interviewee does not know go to 10)*	**8** ACCORDING TO WHAT YOU JUST HAVE SAID, DO YOU THINK THE MICRO-CATCHMENT WHERE YOU LIVE IS HEALTHY? Yes, ...1 No ...2	**9** WHY? ____________________ ____________________ ____________________ ____________________
10 WHAT DO YOU THINK IS THE MAIN HEALTH PROBLEM IN THIS AREA? ____________________ *(If the interviewee cannot identify a problem go to 12)*	**11** WHAT DO YOU THINK IS THE CAUSE OF THIS PROBLEM? ____________________	**12** WHAT DO YOU THINK IS THE MAIN ENVIRONMENTAL PROBLEM IN THIS AREA? ____________________ *(If the interviewee cannot identify a problem go to 14)*
13 WHAT DO YOU THINK IS THE CAUSE OF THIS PROBLEM? ____________________ ____________________	**14** WHAT DO YOU THINK IS THE MAIN WATER PROBLEM IN THIS AREA? ____________________ *(If the interviewee cannot identify a problem go to section J)*	**15** WHAT DO YOU THINK IS THE CAUSE OF THIS PROBLEM? ____________________ ____________________

J. Participation on Health, Environmental or Water initiatives				
		In the last 12 months, you are any of your family members have invested time or money in activities related to *(name alternatives)*? Yes	No	How much do you estimate the investment was in terms of time or money?
1	Improvements to your individual water supply system *(eg. repair leaks, install a tank)*	...1	...2	1.1
2	Improvements to your communal water supply system, including the micro-catchment *(eg. Cleaning the intake, tank, forestation, etc.)*	...1	...2	2.1
3	Improvement the sanitation system *(eg. Excavation, to build an individual wastewater system)*	...1	...2	3.1
4	Improvements to the system of animal excreta management *(eg. Building a biodigester)*	...1	...2	4.1
5	Improvements to the coffee processing management system *(eg. Building a pit)*	...1	...2	5.1
6	Improvement to the system of solid waste management *(eg. building a composting system)*	...1	...2	6.1

K. Agriculture and livelihoods

1 What is the area of your farm?

____

____

Hectares ☐
Plazas ☐
m2 ☐

2 During the past twelve months, any of the household members developed agriculture activities, animal husbandry, or forestry in the farm?

Yes ...1
No ...2
DK / DA ...99

(If the answer is No, continue with 3, otherwise go to 4)

3 What was the reason that prevent from developing these activities?
(Do not read the alternatives to the interviewed)

The profit was low ...1
Health problems ...2
The farm was not habited ...3
Lack of security in the region ...4
Other, which? ______________ ...77
DK / DA ...99
(Go to question 20)

	Name the main three crops in your farm	How much is the area under *(name the crops)*?	Units				
4		4.1	Hectares ☐	Plazas ☐	m^2 ☐	Not applicable ☐	DK/DA ☐
5		4.2	Hectares ☐	Plazas ☐	m^2 ☐	Not applicable ☐	DK/DA ☐
6		4.3	Hectares ☐	Plazas ☐	m^2 ☐	Not applicable ☐	DK/DA ☐

	Changes	Have you changed the crops in your farm in the last 5 years (eg. Coffee to pasture.)?		How much area do you change (name the change)?	Units				
		Yes	No						
7		…1	…2	7.1	Hectares ☐	Plazas☐	m^2 ☐	Not applicable ☐	DK/DA ☐
8		…1	…2	8.1	Hectares ☐	Plazas☐	m^2 ☐	Not applicable ☐	DK/DA ☐
9		…1	…2	9.1	Hectares ☐	Plazas☐	m^2 ☐	Not applicable ☐	DK/DA ☐

	Species	Do you have (name the specie) in your farm?		How many (name the specie) do you have?	The (name the specie) are free or in a pen?		
		Yes	No				
10	Pigs	…1	…2	10.1	10.2	Free …1	Pen …2
11	Chicken	…1	…2	11.1	11.2	Free …1	Pen …2
12	cows	…1	…2	12.1	12.2	Free …1	Pen …2
13	Other, which? _________	…1	…2	13.1	13.2	Free …1	Pen …2

	Inputs	Do you use in your farm (name inputs)?			Cuanta cantidad de (name inputs) usa en su finca?	Units				
		Yes	No	DK / DA						
14	Pesticides	…1	…2	…99	14.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐
15	Herbicides	…1	…2	…99	15.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐
16	Fungicides	…1	…2	…99	16.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐
17	Manure	…1	…2	…99	17.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐
18	Compost	…1	…2	…99	18.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐
19	Other, which? __________	…1	…2	…99	19.1	Kg/month ☐	Ton/year ☐	Other_______ ☐	Not applicable 88 ☐	DK / DA 99 ☐

20 In the last 12 months, apart from this land, the members of this household have taken in lease plots to develop agriculture activities *(Make sure the plot is located within Calabazas micro-catchment)*?

Yes…1 **20.1** How much area? ________________ No …2

L. Health and education

	1 Name of the household members	2 What is the relation between *(name)* with the household head?	3 How old is *(name)*?	4 *(name)* is subscribed to any social security entity? Yes ...1 Go to 5 No ...2 Go to 6 DK / DA ...99 Go to 6	5 What is the social security regime of *(name)*? *(Do not read the alternatives to the interviewed)* Contributor ...1 Subsidized ...2 DK / DA ...99	6 Currently does *(name)* attend school *(attend preschool, school, college, or university)*? Yes 1 Go to 8 No ...2 If he / she is older than 35 Years go to 8, if not, go to 7 DK/DA ...99 Go to 8	7 What is the main reason for *(name)* do not attend school? *(Do not read the alternatives to the interviewed)* He / she thinks that has finished ...1 He / she thinks is not in school age ...2 He / she thinks does not have money ...3 He / she thinks must be in charge of home chores ...4 He / she must work ...5 There is not a school nearby ...6 Other, which? ...77	What is the highest level of education achieved by *(name)* and the last year reached in that level? *(Do not read the alternatives to the interviewed)* None ...1 Preschool ...2 Primary school ...3 High School ...4 Technical ...5 Technological ...6 University ...7 Postgrad ...8 8 Level	9 Last approved year
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

M. Socioeconomic aspects

	1 Name the persons living in this household	2 What is (name) occupation? (Do not read the alternatives to the interviewed) Private employee ...1; Government employee ...2; Domestic employee ...3; Independent worker ...4; Worker in his/her own farm ...5; Worker in his/her own business ...6; Family worker without remuneration ...7; Day-labourer ...8; Unemployed ...9; Retired ...10; Other, which? ...88; *If the answer is 9 continue, otherwise go to 4*	3 Which is the main reason for (name) is unemployed? (Do not read the alternatives to the interviewed) There are no jobs available ...1; He / she does not know how to look for job ...2; He / she is tired from looking for a job ...3; Employers think he / she is too old or too young ...4; Health problems ...5; He / she is studying ...6; Other, which? ...88
1			
2			
3			

4 The household is:

Own, totally paid	...1
Own, is being paid	...2
Rented	...3
In possession, without property rights	...4
DK / DA	...99

5 What of these services the house have?

Electricity	...1
Natural gas from a network	...2
Water supply system	...3
Communal sewer systems	...4
Waste collection	...5

6 How many groups of peoples (homes) prepare food separately in this household? ______________________

7 Including living and dining room, how many rooms this household has? _____________

8 In how many of these rooms do the persons in this house sleep? ___________

N. Observation

1 Predominant material of the outer walls

Block, brick, stone, polished wood	...1
Adobe	...2
Bahareque	...3
Rough wood	...4
Bamboo, cane, other vegetable	...5
Metallic tile, fabric, cardboard, waste plastics	...6
Other, which? ______________________________	...88

2 Predominant material of the floors

Tile, vinyl, brick	...1
Rough wood, other plant	...2
Cement, gravel	...3
Earth, sand	...4
Other, which? ____________________	...88

3 Predominant material of roofs

Straw or palm	...1
Plastics, cardboard	...2
Clay tile, metal tile, without ceiling	...3
Clay tile, metal tile, with ceiling	...4
Other, which? _________________	...88

O. Drinking water samples

1 Would it be possible that in the next days, you provide us a sample of the drinking water from your home? it would be around half a litre to conduct some analysis? This is with the aim to know what is the quality of water you are taking. We will provide the results to you, as soon as we have processed the samples. Yes ...1 No...2

THANK YOU VERY MUCH FOR YOUR TIME!!!

Appendix C Stream water survey data collection forms

Stream water survey			

Date		Monitoring point	

In situ measurements			
Parameter	**Units**	**Reading**	**Comments**
pH			
Temperature			
Conductivity			
Wide of section			
Section scheme			
Stream depths		Velocities	

Analytical results			
Parameter	**Units**	**Reading**	**Comments**
DO			
BOD			
TSS			
Thermotolerant Coliforms			

Appendix D Forms of interviews to water managers

Date ___________________

1. INTRODUCTION

1.1 Interviewed people:

Name	Position	Phone number

2. SYSTEM HISTORY

2.1 ¿When was the water supply system build? _______________________________

2.2 ¿How many people were initially connected?__________________________________

2.3 How many connections does the system have today? ___________________________

2.4 ¿Where the resources to build the system were obtained? __________________________________

2.5 What are the units that comprised the system? ____

2.6 ¿What is the name of the source that supply the system? ____________________________

2.7 ¿How much water is abstracted from the source? _______________________________________

3. SERVICE PROVIDER

3.1. Name of the organization that provides the services: _______________________________________

3.2. When was the organization established? ______________________________________

3.3. Address and telephone number: ____

3.4. Services provided____

3.5. Type of organization: ____

3.6.Legal requirements the organization fulfil:

Legal requirement	Yes	No	Year	Observations
Statutes				
Legal status				
Registration with the Superintendent of Public Utility Services				
Registration with the Regulatory Commission of Water and Sanitation				
Contract of Uniform Conditions				
Service to attend complaints and claims				
Water rights				
Discharge permits				
Other				

3.7. Does the organization have an office to develop their activities? _____________

3.8. The office is: Own ☐ Rented ☐ Borrowed ☐ Other ☐ Which? ________________

3.9 ¿How were the board members elected? ____

3.10 ¿What are the main responsibilities of the Board?

3.11 Information about the members of the Board

3.11.1. Names								
3.11.2 Positions: 1. President 2. Vice-president 3. Secretary 4. Treasurer 5. Auditor 6. Lead vocal 7. System operator 8. Other _____________	|__|	|__|	|__|	|__|	|__|	|__|	|__|	|__|
3.11.3 Gender								
3.11.4 ¿Years in the position?	|__|	|__|	|__|	|__|	|__|	|__|	|__|	|__|
3.11.5 ¿How long is the period of the _________ in the board?								
3.11.6 ¿The ________ has a salary?								
3.11.7. ¿What is the highest educational level attained by ____? 1. Primary 2. Secondary 3. Technical or technological 4. University 5. Post-graduate 7. None 8. DN/DA	|__|	|__|	|__|	|__|	|__|	|__|	|__|	|__|

3.12 Staff

Position	Time in the position	F	M	Time in the organization	Remuneration	Training	
						Yes	No

3.13 How staff salaries are funded? ____

4. COMMUNICATION

4.1. Does the organization celebrate meetings? Yes ☐ How often? __________ No ☐ go to question 4.4

4.2. Who are the people that attend the meetings? ____________________________________

4.3. What are the meeting objectives? A. ______________; B.____________; C._____________

4.4. Administrative and operational activities related to the service provision are planned? __________________

4.5. How are this activities planned? ____

5. EXTERNAL SUPPORT AND TRAINING

5.1 Have the organization received support or donations for ______?		1. ¿Who did provide this support?	2. In average, ¿How much money do this support represent?	3. ¿In which year the support was given?
a. ¿System expansion?				
b. ¿System reparations?				
c. ¿Operation and Maintenance?				
d. ¿Other?				
5.2 ¿In the last two years, have the organization received any training in _______________________?		1. Who did receive this training?	2. ¿Who did provide this training?	3. Approximately how many times training was received in the last 2 years?
a. ¿Operation and maintenance?				
b. ¿Repairs?				
c. ¿Financial management?				
d. ¿Health and hygiene education?				
d. ¿Water quality?				
d. ¿Headwaters protection?				
e. ¿Other?				

5.3 ¿Do you believe, are there aspects in which you require further training than you currently have to improve system management? ____

6. SELF MANAGEMENT

6.1 Have the organization presented projects to improve water services? __________________________

6.2 Projects presented

Project	Institution	Finished		Value	Year
		Yes	No		

6.3 Do you have agreements or contracts with public or private entities? _______________________

6.4 Agreements or contracts

Institutions	Agreement / Contract	Length

7. SYSTEM OPERATION AND MAINTENANCE

7.1. Who is responsible of coordinating and controlling the work of the staff? _______________________

7.2. Does the organization keep records of Operation & Maintenance? _____________________________

7.3. Record of operation and maintenance tasks

Record	Record-keeper	Use of the information

7.4. Does the organization have enough elements to undertake O&M? _______________________

7.5.Has the organization an inventory of elements? ______________________________________

7.6.Has the organization a place to store elements? _______________________________________

7.7 Approximately what percentage of water is believed to be lost in distribution? _____________________

7.8 ¿ Do you have a monitoring system to detect water leaks? (Leaking pipes, illegal connections, etc.)

____

7.9 What is this system about? ________________________________

In case of a problem with the water system, that the organization cannot solve by itself

7.10 ¿ How easy would it be for you to obtain assistance related to…?		7.11 ¿Who would you try to get support from?
a. ¿ Technical aspects, such as a broken pipe?		
b. ¿ Operational or managerial aspects?		
Risk of water pollution caused by human activities		
c. ¿ Financial aspects, for example, if you had to buy expensive spare parts?		
d. Other problem Which: __________________________		

8. COMMERCIAL ASPECTS

8.1. Are there records of systems´ customers?   _________________________

8.2. Is the population in the study area segmented?_________________________

8.3. Is this segmentation used for tariff charges? __________________________

8.4. How are the segments established? ____

8.5. Are there meters in the homesteads? ____

8.6. How many meters are installed? ________________________

8.7. How many meters are working properly? _________________

8.8. What type of tariff is charged for the service? ________________________________

8.9. Which is the tariff? ________________________

8.10. How were water charges established? ____

8.11. How were the current water charges communicated to the public? ____________________________

8.12. Does the organization know whether some customers used alternative supply sources? _________________

8.13. Are there customers using alternative water sources? _____________________________

9. BILLING

9.1. What billing system is in place? ______________________________

9.2. Who is the responsible for billing? ____________________________

9.3. How often the service tariff is charged? ________________________

9.4. Where the charges are collected? _____________________________

9.5 How many customers are delayed in their payments? _________________________

9.6 In average, how many months customers are delayed in their payments? ______________

9.7 How many periods without payment are considered default rate? ______________

9.8 Are there any penalizations for delayed customers? _________________________

9.9 Which are the penalizations? ____

9.10 How many customers were penalized last year? _____________________

9.11 If a new family arrive to the community and request a service connection? The organization will provide this connection? _______________

9.12 ¿How much is the charge for a new connection? ______________________________

10. ACCOUNTING RECORDS

10.1. Please indicate much are the monthly costs of the system in the following aspects:

Salaries: ______________________ Stationery: __________________________

Public services: ______________ Billing: _________________________

Training: _______________ Diem: ____________________________

Water right: ____________ Other: _______________________________

10.2 In your opinion, is the amount of money collected though tariffs - without considering any external support – sufficient to:

a. ¿ Operate and maintain the system? _________________________
b. ¿ Perform minor repairs? _________________________________
c. ¿ Perform major repairs? _________________________________
d. ¿ Extend the distribution network? _________________________
e. Other expenses _______________

10.3 What accounting records and financial reports are made? ___________________________________

10.4. Accounting and financial information is presented to users? ______________________________

10.5. How this information is presented to users? ____

10.6. Who authorizes the expenditures related to the water service? _____________________________

10.7. Where are the collected fees stored? ____

10.8. Are there any funds allocated for training? ____

10.9. Who does receive the training? ____

10.10. What Investments were carried out with last year? ______________________________________

11. EXTERNAL COMMUNICATION

11.1 Does the board holds meetings with the community? ______________________________________

11.2 How often these meetings are held? ____________________________________

11.3 What issues are usually discussed in meetings with the community?___________________________

11.4 Are users informed about the service? ______________________________

11.5 Forms of communication and frequency _____________________________

11.6 There have been conflicts with the community? _______________________

11.7. What kind of conflicts? ____

11.8. How those conflicts have been solved? ____

11.9. What are the most frequent complaints from the community regarding the water supply service?

____

11.10. The organization keeps records of complaints and claims? _____________________________

11.11. Number of complaints and claims presented annually? ________________________________

12. PERCEPTIONS OF WATER QUALITY

12.1 What are the threats you identify to the water quality that you provide? ______________________

12.2 Who generate those threats?____

12.3 What strategies have been implemented to minimize those threats?__________________________

12.4 What would be the solutions to overcome those threats?___________________________________

13. PLANS FOR SYSTEMS´ IMPROVEMENTS

13.1 Are there any plans to undertake system improvements?_____________________________________

13.2 What are the plans? ____

13.3 Approximately how much these improvements will cost? $__________________________________

13.4 What will be the sources of funding for these improvements? ____

13.5 What changes do you think are essential to improve service delivery?________________________________

OBSERVATIONS

Appendix E Forms of inspections to communal water systems

1. GENERAL INFORMATION

1.1 System´s name _________________ 1.2 Date _________________

1.3 People accompanying the inspection ______________________________________

1.4 Start time _____________________ 1.5 Finish time ___________________

1.6 Existent infrastructure

Intake	☐	Transmission pipe	☐
Grit chamber	☐	Transmission pipe 2	☐
Storage tank	☐	Treatment plant	☐
General meter	☐	Distribution network	☐
Household connections	☐		

2. WATER SOURCE

2.1 Type of water source: _____________________

2.2 ¿Have the subscribers received water throughout the year? ___________________

2.3 ¿Why not?__________________________________

2.4 Weather conditions during the inspection: _______________________

2.5 ¿Has the source have water throughout the year? _________________

2.6 ¿Are there any months in which water quantity decrease? ______________________

2.7 ¿Is water quality good enough to be used throughout the year? __________________

If NO, ¿What are the months in which quality is not good enough to be used? _____________

2.8 What is the estimated flow in the source? ________________

2.9 ¿What is the percentage of water available that is abstracted?:__________%

2.10 In the last 2 years, source water quality has…☐ worsen ☐ remained stable ☐ improved

2.11 In the last two years, water quantity has...☐ increased ☐ remained the same ☐decreased

2.12 Geographic coordinates. _______________________________

2.13 is there forest cover protecting around the headwaters? __________________

2.14 What type of forest cover is present? __________________________

2.15 What is the level of forest cover? ____________________________

2.16 is there riparian forest along the source length?__________________

2.17 Is the abstraction area fenced? _______________________________

2.18 is the area around the headwaters owned by the managing organization? ______________

2.19 is there any agreement with the owners of the land around the headwaters? _____________

2.20 What is the degree of erosion around the headwaters? _________________

2.21 Is there any risk of landslides or solids entering before the water abstraction point? _________

2.22 Are there crops surrounding the headwaters? ________________

2.23 What is the extension of those crops? ______________________

2.24 is there evidence of agrochemicals use? ____________________

2.25 Is there presence of livestock surrounding the headwaters? ________________

2.26 Are there settlements surrounding the headwaters? ____________________

2.27 Is there evidence of wastewater discharges before the water abstraction point? ________________

2.28 Is there presence of mining activities before the water abstraction point? ________________

2.29 What are the water uses before the abstraction point? ___________________________________

2.30 Is there presence of point discharges upstream the intake? _____________________

2.31 Is there presence of non-point discharges upstream the intake? _________________

2.32 What strategies are in place to control the identified risks to water quality? ____________________

3. INTAKE STRUCTURE

3.1 Type of the structure ___________________

3.2 ¿is the intake protected (e.g. fenced)? _____________

3.3 ¿Is the protection working? ____________

3.4 Is there a weir or dam that ensure a height of head? ________

3.5 Is there evidence of scouring problems in the channel? ________

3.6 Are there protection walls? _______

3.7 Is there an energy dissipator? _________

3.8 Does the chamber lid facilitate maintenance? _________

3.9 Is the intake grid properly working? __________

3.10 Has the structure being subjected to landslides? _______

3.11 Is it possible to undertake maintenance and continue providing the service? __________

3.12 What is the general condition of the structure? ____

3.13 Maintenance tasks and periodicity

Maintenance task	**Time interval**
Remove sediment and debris from the intake	
Remove sediment and debris from around the intake	
Check or repair cracks or leaks in the structure	
Check or replace damaged or missing parts	
Other tasks	

3.14 Geographic coordinates. ___________________________________

3.15 Flow rate at the inlet intake? ______________________

3.16 Are there significant variations in water quality? ________________________

3.17 What is the cause of the water quality variations? ________________________________

3.18 Are there any strategies to reduce those variations? ___________________________

4. TRANSMISSION PIPES

4.1 How old is the pipeline? _________________

4.2 What is the pipe diameter? ________

4.3 What is the approximate length of the section?______

4.4 What is the pipe material? ______________

4.5 What is the level of leaks? _________________

4.6 What is the size of the leaks? __________

4.7 Are there break-pressure chambers? ______ Quantity: ________Are they working? _________

4.8 Are there purge valves? ______ Quantity: ________Are they working? _________

4.9 Are there vent valves? ______ Quantity: ________Are they working? _________

4.10 Are there special passages? ______ Quantity: ________Are they working? _________

4.11 Are there anchorages? ______ Quantity: ________Are they working? _________

4.12 Is there air entering the pipes? _______________

4.13 Is there any risk of landslides? ________________

4.14 Is there any risk of pollution? ____

4.15 Geographic coordinates ____

5. GRIT CHAMBER

5.1 ¿ How old is the structure? __________________________

5.2 ¿ Which of the following best describes the structure?□ ☐ Over the surface ☐ Buried

5.3 Write the tank´s measures. _________________________________

5.4 Type of grit chamber? _______________________________

5.5 Geographic coordinates. ______________________________

5.6 ¿Which is the main material of the structure? _______________________

5.7 If the tank is covered, ¿What is the material of the cover? __________________________

5.8 Flow entering the tank: ___________________________

5.9 Are there accessories for flow control? __________ Do they work? ____________

5.10 Is there a direct passage pipe? __________ Do they work? ____________

5.11 Is there deflecting baffle? __________ Do they work? ____________

5.12 Is there valve to purge sludge? __________ Do they work? ____________

5.13 Is there overflow structure? __________ Do they work? ____________

5.14 Is there excessive particle build? __________

5.15 Is there risk of landslides? __________

5.16 Is there turbulence in the main compartment? __________

5.17 Is the overflow structure located at the inlet? __________

5.18 Is the overflow structure located at the outlet or in the main compartment? __________

5.19 Is the grit chamber overflowing at the time of the visit? __________

5.20 Is the drainage of the grit chamber properly located? __________

5.21 Is the access area to the grit chamber protected? __________

5.22 Are there pollution risks in the grit chamber? __________

5.23 Is it possible to undertake maintenance and still provide the service? __________

5.24 What is the general condition of the structure? ____

5.25 Maintenance tasks and periodicity

Maintenance task	**Time interval**
Remove sediments	
Undertake shock chlorination to the stored water	
Check and repair fractures and fissures	
Check and replace damaged or missing parts	
Other task:	

6. STORAGE TANK

6.1 ¿How old is the tank? __________________________

6.2 Tank type _____________________

6.3 Tank measurements. _________________________

6.4 Is the tank capacity sufficient to meet the daily demand? ____________________

6.5 Geographic coordinates. _______________________________

6.6 ¿Which is the main material for the tank? ____________________________

6.7 If the tank is covered, ¿What is the material of the cover? _____________________

6.8 Flow entering the tank:________________

6.9 Are there pollution risks to the storage water? ___________

6.10 is the access to the tank´s area restricted? ___________

6.11 Is there infiltration of rainwater? ___________

6.12 Are vent pipes protected? ___________

6.13 Are there flow control valves on the inlet and outlet? ___________

6.14 Are there overflow pipes? ___________

6.15 Is there tank overflow at any time of the day? ___________

6.16 Is the tank drainage adequate? ___________

6.17 Is the tank empty at some point of the day? ___________

6.18 Is it possible to undertake maintenance and continue providing the service? ___________

6.19 ¿ What is the general condition of the structure? _______________________________

6.20 Maintenance tasks and periodicity.

Maintenance task	**Time interval**
Remove sediments	
Undertake shock chlorination to the stored water	
Check and repair fractures and fissures	
Check and replace damaged or missing parts	
Other task:	

7. DISTRIBUTION PIPES

7.1 Are there control valves? ________ Quantity:________ Do they work? ______

7.2 Are there leaks in the control valves? ________

7.3 Are there pressure break chambers? ________ Quantity:________ Do they work? ______

7.4 How many household connections exist? __________________

7.5 Are there micrometres? ________ Quantity:________ Do they work? ______

7.6 Is there macro-meter? ________ Quantity:________ Do they work? ______

7.7 Is the network capacity sufficient to meet the daily requirement? ___________

7.8 Are there zones where the water does not reach? ___________

7.9 Is there water rationing? ___________

7.10 Are there illegal connections? ___________

7.11 Are there visible leaks? ___________

7.12 Are there pollution risks in any section of the pipe? ___________

8. CHLORINATION SYSTEM

8.1 Is the chlorination system in use? ___________

8.2 ¿Why the system is not been used?_______________________________

8.3 If the system is being used, how much is spent on maintenance per year: $________

8.4 ¿How is the chlorination process? ___________________

8.5 In average, ¿ how much chlorine is used monthly?_____________________

8.6 In average, ¿ how much is spent on chlorine monthly? $_________________

8.7 Is there risk of landslides? ___________

8.8 Is there risk of flooding? ___________

OBSERVATIONS

____
____
____
____
____

Appendix F Drinking water survey data collection forms

1 Date		2 Time	
3 Monitoring point			
Analytical results			

Parameter	Units	Result	Comments
4 pH			
5 Turbidity			
6 Thermotolerant Coliforms			
7 Chlorine residual			

8 HAS ANY OF THE FAMILY MEMBERS HAD DIARRHOEA IN THE LAST TWO WEEKS? *(Diarrhoea is determined as perceived by mother or caregiver as three or more loose or watery stools per day, or blood in the stool)*

Yes ...1 No ...2 *If the answer is yes, continue with 9, otherwise finish the questionnaire*

	9 FAMILY MEMBERS WHO HAVE DIARRHOEA IN THE LAST 15 DAYS	10 WHAT IS THE AGE OF *(name)*?	11 *Age units*	12 DURING THE LAST DIARRHOEA EPISODE, DOES *(name)* TAKE ANY BEVERAGE OR MEDICINE? *(Do not read the alternatives to the interviewed)*	13 DURING THE LAST DIARRHOEA EPISODE, ANY HELP OR TREATMENT WAS SOUGHT FOR *(name)* OUT FROM THE HOUSEHOLD?	14 WHERE HELP WAS SEEK FOR *(name)*? *(Do not read the alternatives to the interviewed)*
			Years ...1 Months ...2	Liquid made from a special package ...1 Homemade beverage recommended by some authority ...2 Oral rehydration package ...3 Do not take beverage or medicines ...4 Other, which? ...77 DK / DA ...99	Yes ...1 No ...2 DK / DA ...99 *(If the answer is Yes, go to 14, otherwise finish)*	Public clinic ...1 Public hospital ...2 Private health centre ...3 Friend or relative ...4 Drugstore ...5 Other, which? ...77 DK / DA ...99
1						
2						
3						

Collector of sample ______________________________

Appendix G Income level categories

To categorize households according to income levels the following approach was used:

$$\begin{aligned}Income\ level\ household_x &= (Coffee\ area * income\ factor\ of\ coffee) \\ &+ (Cattle\ units * income\ factor\ of\ cattle) + (pigs\ units * income\ factor\ pigs) \\ &+ (chicken * income\ factor\ chicken)\end{aligned}$$

Income factors for each activity were estimated according to the relative profitability of each activity for 2013, established based on secondary sources and semi-structured interviews discussed in Chapters 4 and 5. The factors used to establish income levels for each household according to main livelihoods in the area were:

Income factor of coffee =2.0

Income factor pigs = 0.2

Income factor cattle = 0.5

Income factor chicken = 0.01

Table G-1 shows the features of households in each income level category.

Table G-1. Features of households in each income level category

Category	Parameters	Coffee area (Ha)	Pasture area (Ha)	Pigs (number)	Poultry (number)	Cows (number)
1	Mean	0.18	0.34	0	1	0
	STD	0.22	0.81	0	2	0
	Median	0.08	0.00	0	0	0
2	Mean	1.28	0.62	1	5	1
	STD	0.63	1.98	2	11	2
	Median	1.28	0.00	0	0	0
3	Mean	2.37	1.14	1	12	1
	STD	0.88	3.01	2	23	2
	Median	2.53	0.00	0	0	0
4	Mean	3.25	5.54	2	4	3
	STD	1.47	10.13	3	9	5
	Median	3.84	0.00	0	0	0
5	Mean	5.75	6.53	0	3	5
	STD	2.94	15.50	1	5	8
	Median	6.02	0.82	0	0	2
6	Mean	9.81	23.47	8	13	24
	STD	9.61	40.65	13	23	28
	Median	10.24	0.00	0	0	18

Appendix H Changes on water quality from distribution tanks to households in communal systems

Table H1- Statistical tests comparing TTC levels between storage tanks and households

Season	Water systems	Median TTC (CFU/100 ml)		Mann-Whitney test p-value
		Tanks	Households	
Dry	Acuacalabazas	45	30	0.364
	Acuamiravalle	33	22	0.853
	Calabazas	39	28	0.293
Rainy	Acuacalabazas	69	28	0.087
	Acuamiravalle	42	25	0.650
	Calabazas	21	18	0.609

Appendix I Focus groups agenda

Table I-1. Agenda for the first focus group meeting

Time	Activities	Responsible
8:00 – 8:15	Salutation, Background, Objectives, Agenda	Isabel Domínguez
8:15 – 8:30	Presentation of members, and guidelines for the meeting	Inés Restrepo
8:30 – 8:45	Systems thinking, System dynamics, and Stella Software	Isabel Domínguez
8:45 – 9:05	Ideas to explore with modelling, envisioning exercise, and sectors identification	Inés Restrepo
9:05 – 9:15	Scale issues in Systems Dynamics Modelling	Isabel Domínguez
9:15 – 9:30	Reservoir identification	Inés Restrepo
9:30 – 10:00	Identification of relations, reference modes of behaviour	Inés Restrepo
10:00 – 10:30	Synthesis and follow up	Isabel Domínguez

Appendix J Summary of focus groups sessions

Table J-1. Summary of Focus Groups

Focus Group	Attendees codes	Affiliations	Position	Issues covered
Focus Group Session 1 (22/11/12)	C1[28]	DCC	Director of extension programs *(Gatekeeper)*	The background, objectives and rationale for the meeting were explained as well as the guidelines for the meeting. The gatekeeper provided his team with a rationale for the Federation to support the research. The PhD student presented aspects of Systems thinking, System dynamics, and Stella Software. Group exercises were developed to identify “ideas to be explored using modelling”, and around: envisioning, sectors, reservoirs, linkages, and reference modes of behaviour identification. The meeting concluded with a synthesis of the outcomes and planning for the next session.
	C4	DCC	Economic coordinator	
	C5	DCC	Environmental coordinator	
	C2	DCC	Social coordinator	
	C3	DCC	Ecological coffee processing	
	C6	DCC	Extension coordinator	
	Ines Restrepo	Universidad del Valle	Local supervisor	
	Paola Chaves	Wageningen University	Note-keeper	
	Isabel Dominguez	Newcastle University	System modeller – PhD student	
Focus Group Session 2 (29/11/12)	C1	DCC	Director of extension programs	C8 who is the successor of C1 after his retirement was introduced to the collaboration Project and he was involved in the model development during this meeting. Model sectors developed during the last meeting, especially: land use, economic and population sectors were discussed and adjusted based on the discussion with the participants. The meeting concluded with a synthesis of the outcomes and planning for the next session.
	C8	DCC	Director of extension programs (successor)	
	C4	DCC	Economic coordinator	
	C2	DCC	Social coordinator	
	C6	DCC	Extension coordinator	
	Paola Chaves	Wageningen University	Note-keeper	
	Isabel Dominguez	Newcastle University	System modeller - PhD student	
Focus Group Session 3 (3/12/12)	C4	DCC	Economic coordinator	Updating C7 with the progress on the model development at that point, discussion and feedback. We discuss and update model sectors not addressed in the second meeting: population, pollution, people health, management sector and amenities. It was agreed to program meetings with C7 and C4 to discuss the quantitative information that is currently available for the model from the Coffee Growers Federation, and further steps.
	C5	DCC	Environmental coordinator	
	C2	DCC	Social coordinator	
	C7	DCC	Information Systems coordinator	
	C6	DCC	Extension coordinator	
	Isabel Dominguez	Newcastle University	System modeller - PhD student	

[28] C means that the stakeholder belongs to the Departmental Committee of Coffee Growers of Valle del Cauca, the number is to distinguish different people within the organization.

Appendix K Sources of secondary information

Table K-1. Sources of secondary information

National	Regional	Local
• Ministry of Agriculture • Ministry of Social Protection • Ministry of Environment and Sustainable Development • National Planning Department • National Bank • Financial Superintendence • National Institute of Health • National Department of Statistics • Institute of Hydrology, Meteorology and Environmental Studies • National Federation of Coffee Growers • National Federation of Livestock • National Corporation of Research and Forestry Development	• Environmental Authority for the Valle del Cauca Department • Implementing unit sanitation of Valle del Cauca • Departmental Committee of Coffee Growers of Valle del Cauca	• General Hospital Riofrío • Municipality of Riofrío

Appendix L Second round of semi-structured interviews

Table L-1. Second round of semi-structured interviews conducted for model building

Date	Stakeholder[29]	Academic background	Filiation	Field	Sectors covered
13/12/2012	C7	Agronomists, specialist in GIS	DCC	Coffee Information System manager	Land use and economic
18/12/2012	C4	Economist	DCC	Economic coordinator	Economic
04/01/2013	C5	Sanitary Engineer	DCC	Environmental coordinator	Management
21/01/2013	E1	Sanitary Engineer	CVC	Environmental resources planning	Management
09/05/2013	E1	Sanitary Engineer	CVC	Environmental resources planning	Stream health
13/01/14	C3	Agricultural Engineer	DCC	Environmental coordinator	Economic
13/01/14	E1	Sanitary engineer	DCC	Environmental resources planning	Management and stream health
14/01/14	R2	Sanitary engineer	Universidad Autónoma de Occidente	Water quality specialist	Stream health
15/01/14	E4	Forest Engineering	CVC	GIS manager	Land use
15/01/14	E5	Lawyer	CVC	Payment for environmental services	Management
15/01/14	E6	Agriculture engineer	CVC	Hydrologists	Stream health
15/01/14	C4	Economist	DCC	Economic coordinator	Management
16/01/14	R1	Veterinarian, Ph.D. in Aquatic ecology	CIPAV	Sustainable livestock researcher	Economic, land use, stream health and management
17/01/14	C12	Agronomist	DCC	Biodiversity in coffee regions	Land use

29 C means that the stakeholder belongs to the Departmental Committee of Coffee Growers of Valle del Cauca, E is for stakeholders from the Environmental Authority. R for stakeholders from research institutions. F for stakeholders from the Livestock farmers Federation. G is for stakeholders from the local government. The numbers are to distinguish different people within the organizations.

Date	Stakeholder[29]	Academic background	Filiation	Field	Sectors covered
17/01/14	C11	Agricultural Engineer	DCC	Extension worker for *Calabazas*	Economic, stream health and management
17/01/14	C7	Systems engineer	DCC	GIS manager	Economic and land use
17/01/14	C2	Business manager	DCC	Social coordinator	Economic
22/01/14	F2	Veterinarian	Cogancevalle	Capacity development programs	Economic, land use, stream health and management
22/01/14	G2	Statistician	Riofrío local hospital	Health statistics manager	Human health
23/01/14	G3	Natural resources technician	Agriculture secretary Riofrío municipality	Responsible for environmental issues and agricultural development	Land use, economic and management
24/01/14	C13	Agronomist, specialist in business management	DCC	Specialist in coffee production costs	Economic
25/01/14	C10	Agronomist	DCC	Extension worker for *Calabazas*	Economic, stream health and management
27/01/14	R3	Biologists, PhD in Microbial Ecology	Universidad del Valle	Teaching and research in microbiology	Stream health and human health
27/01/14	R4	Sanitary Engineer, Master in Health Administration and PhD in Engineering	Universidad del Valle	Teaching and research in public health	Human health

Appendix M Equations to obtain values for the year 2013 in some model parameters

Population sector

$coffe\ employment = coffee\ area * coffee\ employment\ factor$

$livestock\ employment\ factor\ per\ area = livestock\ density * livestock\ employment\ factor$

$livestock\ employment = Pasture\ area * livestock\ employment\ factor\ per\ area$

$commercial\ forest\ employment = Commercial\ forest\ area * commercial\ forest\ employment\ factor$

$occupied\ population = commercial\ forest\ employment + livestock\ employment + coffee\ employment$

$working\ age\ population = Population * fraction\ of\ working\ age\ population$

$ratio\ occupied\ population\ working\ age\ population = \frac{occupied\ population}{working\ age\ population}$

$population\ growth = birth\ rate * Population$

$population\ decrease = death\ rate * Population$

$emigration = unsatisfied\ basic\ needs\ effect * Population$

Economic sector - Coffee farmers’ profitability module

$national\ coffee\ price = international\ colombian\ coffee\ price * exchange\ rate$

$difference\ ceiling\ and\ national\ price = price\ ceiling - national\ coffee\ price$

$subsidies\ to\ coffee\ price = IF(difference\ ceiling\ and\ national\ price > 0) THEN\ difference\ ceiling\ and\ national\ price\ ELSE\ 0$

$subsidized\ coffee\ price = national\ coffee\ price + subsidies\ to\ coffee\ price$

$income\ coffee = yield * average\ coffee\ farm * subsidized\ coffee\ price$

$production\ costs\ coffee = average\ coffee\ farm * yield * costs\ per\ coffee\ production$

$coffee\ profitability = income\ coffee - production\ costs\ coffee$[30]

Economic sector - Resources to the National Coffee Fund Module

$coffee\ production = coffee\ area * yield$

$produced\ coffee = coffee\ production$[30]

$exported\ coffee = produced\ coffee * proportion\ of\ coffee\ exports$

$income\ from\ coffee\ contribution = exported\ coffee * coffee\ contribution * exchange\ rate$

$income\ from\ other\ sources\ of\ funding = ratio\ CC\ other\ sources * income\ from\ coffee\ contribution$

$income\ to\ National\ Coffee\ Fund = income\ from\ coffee\ contribution + income\ from\ other\ sources\ of\ funding$

$resources\ National\ Coffee\ Fund = income\ to\ National\ Coffee\ Fund$[30]

30 This is the initial value for 2013 because the dynamic equation for this Stock was not written

$$Resources\ catchment\ coffee\ committee$$
$$= Resources\ National\ coffee\ fund$$
$$* percentage\ of\ investment\ in\ environmental\ programs$$

Economic sector - Livestock farming

$$livestock\ quantity\ farm = livestock\ density * average\ livestock\ farm$$

$$produced\ milk = livestock\ quantity\ farm * proportion\ of\ milk\ cows * milk\ productivity$$

$$milk\ income = produced\ milk * milk\ price * percentage\ for\ sale$$

$$produced\ meat = average\ livestock\ farm * meat\ productivity$$

$$meat\ income = produced\ meat * meat\ price$$

$$livestock\ income = meat\ income + milk\ income$$

$$milk\ production\ costs$$
$$= produced\ milk * livestock\ costs\ per\ produced\ milk * percentage\ for\ sale$$

$$meat\ production\ costs = livestock\ costs\ per\ kg * produced\ meat$$

$$livestock\ production\ costs = milk\ production\ costs + meat\ production\ costs$$

$$livestock\ profitability = livestock\ income - livestock\ production\ costs$$ [31]

Economic sector - Commercial forestry

$$woodpulp\ income = Commercial\ forest\ area * commercial\ forest\ productivity * woodpulp\ price$$

$$income\ from\ subsidies = Commercial\ forest\ area * subsidies\ commercial\ forest$$

$$commercial\ forest\ production\ costs$$
$$= Commercial\ forest\ area * costs\ per\ unit\ commercial\ forest$$

$$Commercial\ forest\ profitability = commercial\ forest\ income - commercial\ forest\ production\ costs$$ [31]

Land use sector

$$coffee\ profitability\ per\ area = \frac{Coffee\ profitability}{average\ area\ coffee\ farm}$$

$$coffee\ transformation = coffee\ area\ demand * Total\ area$$

$$commercial\ forest\ profitability\ per\ area = \frac{Commercial\ forest\ profitability}{Commercial\ forest\ area}$$

$$commercial\ forest\ transformation = commercial\ forest\ area\ demand * Total\ area$$

$$livestock\ profitability\ per\ area = \frac{Livestock\ profitability}{average\ livestock\ farm}$$

$$pasture\ transformation = pasture\ area\ demand * Total\ area$$

$$natural\ forest\ transformation = natural\ forest\ area\ demand * Total\ area$$

[31] This is the initial value for 2013 because the dynamic equation for this Stock was not written

Stream health sector - BOD module

$$BOD\ domestic\ wastewater = percapita\ load\ BOD * Population * BMPs\ BOD\ domestic\ wastewater$$

$$number\ of\ households = \frac{Population}{household\ size}$$

$$number\ of\ households\ with\ pigs = number\ of\ households * proportion\ of\ households\ with\ pigs$$

$$pigs = number\ of\ households\ with\ pigs * average\ pigs\ per\ household$$

$$raising\ pigs = pigs * proportion\ of\ pigs\ in\ raise$$

$$lactating\ females = pigs * proportion\ of\ lactating\ females$$

$$live - weight\ pigs = (raising\ pigs * weight\ pigs\ in\ raise) + (lactating\ females * weight\ lactating\ females)$$

$$BODpigs = live - weight\ pigs * factor\ BOD\ per\ live - weight\ pigs$$

$$BOD\ coffee\ processing = produced\ coffee * ratio\ kg\ cherry\ coffee\ kg\ coffee * BOD\ load\ coffee\ processing * BMPs\ BOD\ coffee\ processing$$

$$BOD\ multiple\ sources = BOD\ domestic\ water + BOD\ pigs + BOD\ coffee\ processing$$

$$BOD = BOD\ multiple\ sources$$[32]

$$BOD\ stream\ outlet = \frac{BOD}{stream\ flow} * selfpurification\ effect$$

Stream health sector - TSS module

$$TSS\ piggeries = liveweight\ pigs * TSS\ load\ per\ pig * BMPs\ TSS\ piggeries$$

$$TSS\ pasture = pasture\ area * TSS\ load\ area\ under\ pasture * natural\ sedimentation$$

$$TSS\ coffee\ area = coffee\ area * TSS\ load\ coffee\ area * natural\ sedimentation$$

$$TSS\ domestic\ water = Population * percapita\ load\ TSS * BMPs\ TSS\ domestic\ water$$

$$TSS\ coffee\ processing = produced\ coffee * TSS\ load\ coffee\ processing * water\ used\ in\ coffee\ processing * BMPs\ coffee\ processing$$

$$TSS\ multiple\ sources = TSS\ piggeries + TSS\ commercial\ forest + TSS\ coffee\ area + TSS\ domestic\ wastewater + TSS\ coffee\ processing$$

$$TSS = TSS\ multiple\ sources$$[32]

$$TSS\ stream\ outlet = \frac{TSS\ multiple\ sources}{stream\ flow}$$

Stream health sector - TTC module

$$TTC\ domestic\ water = Population * percapita\ TTC\ load * BMPs\ domestic\ wastewater$$

[32] This is the initial value for 2013 because the dynamic equation for this Stock was not written

$$TTC\ piggeries = pigs * TTC\ load\ pig\ slurry * cleaning\ water * BMPs\ TTC\ piggeries$$

$$livestock\ quantity = Pasture\ area * livestock\ density$$

$$TTC\ livestck\ farms = livestock\ quantity * TTC\ load\ per\ livestock\ unit * proportion\ of\ manure\ to\ stream * BMPs\ TTC\ livestock$$

$$TTC\ multiple\ sources = TTC\ domestic\ wastewater + TTC\ piggeries + TTC\ livestock\ farms$$

$TTC = TTC\ multiple\ sources$[33]

$$TTC\ stream\ outlet = \frac{TTC}{stream\ flow} * dieoff\ effect$$

Human health sector

$$TTC\ at\ headwaters = TTC\ stream\ outlet * ratio\ TTC\ headwaters\ outlet$$

$$pathogen\ bacteria\ at\ households = TTC\ at\ headwaters * ratio\ TTC\ headwaters\ to\ households * proportion\ E.coli * proportion\ of\ pathogenic\ E.coli$$

$$pathogen\ exposure\ by\ drinking\ water = pathogen\ bacteria\ at\ households * volume\ of\ water\ consumed$$

$$probability\ of\ infection = 1 - [1 - (pathogen\ exposure\ by\ drinking\ water * probability\ that\ exposure\ results\ in\ infection)]^{365}$$

$$Risk\ of\ disease = probability\ of\ infection * probability\ of\ disease\ given\ infection$$

$$susceptible\ fraction = (1 - coverage\ improved\ systems) * (1 - BMPs\ at\ household\ level)$$

$$New\ cases\ of\ diarrhoea = Population * susceptible\ fraction * risk\ of\ disease$$

$Cases\ of\ diarrhoea = New\ cases\ od\ diarrhoea$[33]

$$diarrhoea\ cases\ seeking\ healthcare = cases\ of\ diarrhoea * rate\ of\ healthcare\ seking\ for\ diarrhoea$$

$Reported\ cases\ diarrhoea = diarrhoea\ cases\ seeking\ healthcare$[33]

Management sector

$$Resources\ coffee\ families = IF(minimum\ national\ legal\ wage - coffee\ profitability > 0)THEN(minimum\ national\ legal\ wage - coffee\ profitability)ELSE0$$

$$Resources\ livestock\ families = IF(minimum\ national\ legal\ wage - livestock\ profitability > 0)THEN(minimum\ national\ legal\ wage - livestock\ profitability)ELSE0$$

[33] This is the initial value for 2013 because the dynamic equation for this Stock was not written

$$
\begin{aligned}
&Resources\ for\ catchment\ and\ human\ health \\
&\qquad = resources\ coffee\ families + resources\ environmental\ authority \\
&\qquad + resources\ catchment\ coffee\ committee + resources\ municipality \\
&\qquad + resources\ livestock\ families + resources\ water\ committees \\
&\qquad + resources\ sanitation\ unit \\
&Budget\ catchment\ health\ human\ health \\
&\qquad = Resources\ for\ catchment\ health\ and\ human\ health
\end{aligned}
$$
[34]

[34] This is the initial value for 2013 because the dynamic equation for this Stock was not written

Appendix N Glossary

Agriculture intensification
A process whereby inputs of capital and/or labour are increased to raise the productivity or yield of a fixed land area.
Source: Börjeson, L. (2010) Agricultural Intensification. Encyclopedia of Geography. SAGE Publications, Inc. Thousand Oaks, CA: SAGE Publications, Inc.

Best Management Practices
Methods or techniques found to be the most effective and practical means in achieving an objective (such as preventing or minimizing pollution) while making the optimum use of the firm's resources.
Source: http://www.businessdictionary.com

Biochemical Oxygen Demand
Standard method for indirect measurement of the amount of organic pollution (that can be oxidized biologically) in a sample of water. The result of a BOD test indicates the amount of water-dissolved oxygen consumed by microbes incubated in darkness for five days at an ambient temperature of 20°C.
Source: http://www.businessdictionary.com

Cash crop
A crop grown for sale rather than for subsistence.
Source: http://dictionary.reference.com

Causal Loop Diagram
A diagram that shows a collection of connected nodes and the feedback loops created by the connections, used to explain the behaviour of a system.
Source: http://www.thwink.org/sustain/glossary

Cherry coffee
The fruit of any plant of the genus *Coffea* being cherry-like in shape, colour, and size and containing two seeds enclosed by pulp and an outer skin.
Source: http://www.merriam-webster.com

Clean crop
Crop that is carried out in lands for intensive farming, suitable for diversified crops and with the greatest agricultural quality.
Source: http://ciencia.glosario.net/agricultura

Coffee processing
Process of removing coffee beans from the fruit and dry them before they can be roasted.
Source: http://www.ico.org

Coffee renovation
Strategy in which plots within a coffee farm are planted with new trees to keep the whole plantation with an average age that ensure optimal yields.

Default rate
An interest rate institutions will charge to those customers who are not making payments on their obligations, as well as to those who are late on their payments.
Source: http://www.businessdictionary.com

Demographic transition
Economic theory that links population changes to levels of economic, education, and healthcare development. It states that as women become better educated and financially independent, the global fertility rates will continue to decline. Low birth rates combined with low death rates (due to better health care and nutrition) will result in an increasing number of older people dependent on pension schemes.
Source: http://www.businessdictionary.com

Dense crop
Cereals, grasses and legumes that can be planted by scattering or planter with a distance of 15 or 20 cm.
Source: http://ciencia.glosario.net/agricultura

Diarrhoea
The passage of three or more loose or liquid stools per day (or more frequent passage than is normal for the individual). Diarrhoea is usually a symptom of an infection in the intestinal tract, which can be caused by a variety of bacterial, viral and parasitic organisms. Infection is spread through contaminated food or drinking-water, or from person-to-person as a result of poor hygiene.
Source: http://www.who.int/mediacentre

Die-off
A sudden, severe decline in a population or community of organisms as a result of natural causes.
Source: http://www.thefreedictionary.com

Dissolved Oxygen
Amount of oxygen dissolved (and hence available to sustain life) in a body of water such as a lake, river, or stream. It is the most important indicator of the health of a water body and its capacity to support a balanced aquatic ecosystem of plants and animals.
Source: http://www.businessdictionary.com

District
Managerial unit to provide services to farmers in the National Coffee Federation.

Dry parchment coffee
The green coffee bean contained in the parchment skin that has been subject to a drying process.

E. Coli
One of several types of bacteria that normally inhabit the intestine of humans and animals. Some strains are capable of causing disease under certain conditions when the immune system is compromised or disease may result from an environmental exposure.
Source: http://medical-dictionary.thefreedictionary.com/

Ecosystem services (Environmental services)
The important benefits for human beings that arise from healthily functioning ecosystems, such as production of oxygen, soil genesis, and water purification.
Source: http://dictionary.reference.com/

Endemic
Referring to the usual prevalence of a given disease or infection in an area or group. Endemic conditions do not exhibit wide fluctuations over time in a defined place.
Source: http://medical-dictionary.thefreedictionary.com/endemic

Exchange rate
Price for which the currency of a country can be exchanged for another country's currency.
Source: http://www.businessdictionary.com

Extension worker
Intermediaries between research and farmers. They operate as facilitators and communicators, helping farmers in their decision-making and ensuring that appropriate knowledge is implemented to obtain the best results.
Source: http://www.gostudy.

Feedback loop
A system structure that causes output from one node to eventually influence input to that node.
Source: http://www.thwink.org/sustain/glossary/

Free exposure coffee
Coffee grown in systems where the effect of the regulation of the incident light comes from any permanent arboreal species less than 20 trees per hectare or less than 300 permanent shrub species.
Source: Khalajabadi, S. (n.d.) Calibración de análisis de suelo en cafetales al sol y bajo semi-sombra. Chinchiná (Colombia).

Gatekeeper
The person who controls research access. For example, the top manager or senior executive in an organization, or the person within a group or community who makes the final decision as to whether to allow the researcher access to undertake the research.
Source: http://srmo.sagepub.com/view/the-sage-dictionary-of-social-research-methods/

Gini coefficient
A measure of inequality of income or wealth.
Source: http://encyclopedia.thefreedictionary.com/

Green revolution
Series of research, development, and technology transfer initiatives, occurring between the 1940s and the late 1970s, that increased agriculture production worldwide, particularly in the developing world. The initiatives involved the development of high-yielding varieties of cereal grains, expansion of irrigation infrastructure, modernization of management techniques, distribution of hybridized seeds, synthetic fertilizers, and pesticides to farmers.
Source: http://encyclopedia.thefreedictionary.com/

Gross Domestic Product (GDP)
The value of a country's overall output of goods and services (typically during one fiscal year) at market prices, excluding net income from abroad.
Source: http://www.businessdictionary.com

Healthcare
Diagnosis, treatment, and prevention of disease, illness, injury, and other physical and mental impairments in humans. Health care refers to the work done in providing primary care, secondary care, and tertiary care, as well as in public health.
Source: http://encyclopedia.thefreedictionary.com

Improved sanitation
Having a toilet in the premises that safely manage excreta.
Source: WHO/UNICEF (2013) *Progress on sanitation and drinking-water* - 2013 update. Geneva.

Improved water source
A drinking-water source which by nature, construction or active intervention, is protected from outside contamination, in particular from contamination with faecal matter.
Source: WHO/UNICEF (2013) *Progress on sanitation and drinking-water* - 2013 update. Geneva.

Infectious disease
A disease caused by a microorganism or other agent, such as a bacterium, fungus, or virus that enters the body of an organism.
Source: http://www.thefreedictionary.com

Lactating pigs
Pigs with an average weight of 190 kilos.
Source: Minambiente (2002) Guia Ambiental para el Subsector Porcicola. Bogotá, D.C.

Land for recovery
Land with severe and very severe erosion and high susceptibility to soil loss, which due to its natural condition and geographical location has high economic, social or environmental value.
Source: CVC (2013) Guía rápida temática para el usuario SIG corporativo uso potencial y zonificación forestal. Cali (Colombia).

Live-weight
The weight of an animal while living.
Source: http://www.merriam-webster.com/dictionary

Medical insurance
Insurance against expenses incurred through illness of the insured.
Source: http://www.thefreedictionary.com/

Mixed methods approach
An approach to research that combines the collection and analysis of quantitative and qualitative data.
Source: http://www.thefreedictionary.com/

Morbidity
Departure from a state of physical or psychological well-being, resulting from disease, illness, injury, or sickness, especially where the affected individual is aware of his or her condition.
Source: http://www.businessdictionary.com

Mortality
Relative incidence of death within a particular group categorized according to age or some other factor such as occupation.
Source: http://www.businessdictionary.com

Multidimensional poverty index
Index that complements monetary measures of poverty by considering overlapping deprivations suffered by people at the same time. These deprivations are related to the dimensions of health, education and standard of living. The index shows the number of people who are multi-dimensionally poor (suffering deprivations in 33% of weighted indicators) and the number of deprivations with which poor households typically contend with.
Source: http://hdr.undp.org/en

Multilayer crop
Crop that provide coverage to the soil such as coffee and cocoa with shade, and some fruit trees. These crops require soil conservation practices, which must be done by hand.
Source: CVC (2013) Guía rápida temática para el usuario SIG corporativo uso potencial y zonificación forestal. Cali (Colombia).

Odds Pact
Market intervention to control coffee price that extended up to 1989.
Source: Cano, C., Vallejo, C., Caicedo, E., Amador, J. and Tique, E. (2012) 'El mercado mundial de café y su impacto en Colombia', Borradores de economía, (710), pp. 1-56.

Outlier
Statistical data which is extremely different from the others in the same sample.
Source: http://www.businessdictionary.com

Pathogenic E. Coli
E. coli that can cause illness, either diarrhoea or illness outside of the intestinal tract. The types of E. coli that can cause diarrhoea can be transmitted through contaminated water or food, or through contact with animals or persons.
Source: http://www.cdc.gov

Payment for environmental services
A mechanism to improve the provision of indirect environmental services in which those who provide environmental services get paid and those who benefit from environmental services pay for their provision.
Source: Pagiola, S., Agostini, P., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., Ramírez, E., Rosales, M. and Ruíz, J. P. (2005) 'Paying for biodiversity conservation services: Experience in Colombia, Costa Rica, and Nicaragua', Mountain Research and Development, 25(3), pp. 206-211.

Period prevalence
Proportion of a population that has a disease condition at some time during a given period, and includes people who already have the condition at the start of the study period as well as those who acquire it during that period.
Source: http://encyclopedia.thefreedictionary.com

pH
Measure of the acidity or basicity of an aqueous solution.
Source: http://encyclopedia.thefreedictionary.com

Pigs in raise
Pigs from 22 – 25 kilos to 50 – 60 kilos.
Source: Minambiente (2002) Guia Ambiental para el Subsector Porcicola. Bogotá, D.C.

Prevalence.
Proportion of a population found to have a condition (typically a disease or a risk factor). It is arrived at by comparing the number of people found to have the condition with the total number of people studied, and is usually expressed as a fraction, as a percentage or as the number of cases per 10,000 or 100,000 people.
Source: http://encyclopedia.thefreedictionary.com

Price ceiling
Government-imposed price control or limit on how a price is charged for a product.
Source: http://encyclopedia.thefreedictionary.com

Productive forest
Forest for the production of timber and other forest products.
Source: CVC (2013) Guía rápida temática para el usuario SIG corporativo uso potencial y zonificación forestal. Cali (Colombia).

Protective forest
Natural forests that must be protected to enhance the restoration of ecosystem services.
Source: CVC (2013) Guía rápida temática para el usuario SIG corporativo uso potencial y zonificación forestal. Cali (Colombia).

Revaluation
Upward adjustment in the value of currency with respect to another currency or a benchmark rate of exchange.
Source: http://www.businessdictionary.com

Self-purification
Naturally produced purification.
Source: http://www.thefreedictionary.com/

Semi-clean crops
Crops that allow sowing, ploughing, harvesting or grazing for long growing seasons (perennial), do not require frequent and continuous removal of soil, and allow a permanent vegetation cover except between plants or short seasonal periods.
Source: CVC (2013) Guía rápida temática para el usuario SIG corporativo uso potencial y zonificación forestal. Cali (Colombia).

Shade-grown coffee
Coffee grown in poly-culture systems, under forest cover, mimicking the old growth forests that provide habitat, particularly for migratory birds and mammals. The advantages of shade-grown coffee include the regulation of external temperatures, decreased evapotranspiration, soil conservation, reduced effect of the winds, and regulation of nutrient cycling.
Source: www.ihcafe.hn

Silvopastoral systems
A deliberate combination of trees, pastures, and livestock.
Source: http://encyclopediaofforestry.org

Slurry
A mixture of animal waste, other organic material and sometimes water.
Source: http://www.yourdictionary.com

Snowball sampling
Sampling approach that uses a small pool of initial informants to nominate other.
Source: http://srmo.sagepub.com

Subsistence crop
Crop planted by farmers to feed themselves and their families.
Source: http://encyclopedia.thefreedictionary.com

Technified coffee
Coffee production system characterized by the removal of forest cover, modifying the microclimate at the level of the coffee plant, higher densities, use of new varieties and increased use of agrochemicals.
Source: www.ihcafe.hn

Thermotolerant Coliforms (TTC)
The group of coliform bacteria which produce gas from lactose in 48 hours at 44.5ºC.
Source: http://www.iadclexicon.org

Total Suspended Solids (TSS)
Water quality parameter estimated through the measurement of the weight of particles trapped by a filter of a specified pore size.
Source: http://encyclopedia.thefreedictionary.com

Triangulation
In the social sciences, triangulation refers to the application and combination of several research methodologies in the study of the same phenomenon. It facilitates validation of data through cross verification from two or more sources, and it is used as an alternative to traditional criteria like reliability and validity.
Source: http://encyclopedia.thefreedictionary.com

Turbidity
Cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air.
Source: http://encyclopedia.thefreedictionary.com

Yield
The measure of grains or seeds generated from a unit of land expressed as kilograms per hectare. Also called agricultural output.
Source: http://www.businessdictionary.com