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The water footprint of coffee production in Miraflor, Nicaragua

Vattenfotavtrycket för produktionen av kaffe i Miraflor, Nicaragua

Emma Moberg

ABSTRACT

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Emma Moberg

A water footprint is a tool for assessing the impacts of freshwater use by mapping the water use of the production of a good or a service, a process in a production chain, a business or even of a whole country. One of the most commonly used methods for calculating the water footprint was developed by the Water Footprint Network (WFN). The objective of this study was to account for the water footprint of the production of coffee in the area of Miraflor, Nicaragua, using the WFN method. The study aimed to highlight where improvements can be made regarding water resources management, both with respect to the quantity of the water appropriated in the different process steps, as well as concerning the treatment of residues of the coffee production.

The results of the study show a water footprint of 20 049 m^3 per ton of harvested coffee in Miraflor. This equals a consumption of more than 6 000 000 m^3 of water when considering the overall production of the harvest of 2015/2016. The results pinpoint the growing phase as crucial with 98.1 % of the total water footprint. Nicaragua and the region where Miraflor is located are having increasing problems with water scarcity due to drought and contamination of water resources. Together with these circumstances, the results of the study show that the current management should be improved in order to minimize the impacts on local water resources and the environment. It is mainly the application of pesticides and fertilizers in the cultivation of the coffee that give rise to the large water footprint. Furthermore, the current management violates the law restricting the discharge of effluent waters from coffee processing plants. Another important factor contributing to the water footprint yields in the consumption of rainwater via evapotranspiration by the crops in field.

In order to reduce the water footprint there should be a more conscious use of pesticides and fertilizers as well as a development in the treatment of the effluent water. The latter factor can be elaborated by considering new installations where even smaller ones probably could make a considerable change. Other management practices to decrease the water footprint consist of generating a higher yield per hectare of land.

Keywords: Water footprint, water footprint assessment, consumptive water use, water pollution, Nicaragua, coffee,

Department of Earth Sciences, Program for Air, Water and Landscape Sciences, Uppsala University. Villavägen 16, SE-752 36 Uppsala

REFERAT

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Vattenfotavtryck är ett verktyg för att bedöma miljöpåverkan från användningen av vatten. Med ett vattenfotavtryck kartläggs hur vatten används för produktionen av en vara, för en process i en produktionskedja, ett företag eller för ett helt land. En av de mest använda metoderna för beräkning av vattenfotavtryck utvecklades av Water Footprint Network (WFN). Syftet med denna studie var att genom användning av WFN:s metod beräkna vattenfotavtrycket för produktionen av kaffe i området Miraflor i Nicaragua. Studien ämnade visa var förbättringar kan göras i vattenresurshanteringen, både vad gäller mängden vatten som används i de olika produktionsstegen som i behandlingen av restvattnet från kaffeproduktionen.

Resultatet från studien visar ett vattenfotavtryck på 20 049 m^3 per ton skördat kaffe i Miraflor. Sett till hela skörden för säsongen 2015/2016 ger detta ger en total konsumtion av mer än 6 000 000 m^3 vatten. Resultatet påvisar att vegetationsperioden är den i särklass största bidragande faktorn till kaffeproduktionens vattenfotavtryck med 98,1 % av det totala avtrycket. Nicaragua och regionen där Miraflor ligger har alltjämt ökande problem med vattenbrist på grund av torka och föroreningar av vattenresurser. Studiens resultat visar tillsammans med denna bakgrund att nuvarande tekniker i kaffeproduktionen i Miraflor bör förbättras för att minimera konsekvenser för lokala vattenresurser och miljön. Främst är det användningen av bekämpningsmedel och gödsel som ger upphov till det stora vattenfotavtrycket. Kaffeproduktionen orsakar därtill överträdelser av gällande bestämmelser om värden på vattenkvalitetsparameterar i restvatten från kaffeproduktion. En ytterligare betydande faktor för vattenfotavtrycket som påvisas i studien är konsumtionen av regnvatten via evapotranspiration från grödorna i fält.

För att minska vattenfotavtrycket bör i första hand en mer medveten användning av bekämpningsmedel och gödsel införas. Därtill bör det ske en förbättring i hanteringen av utsläppsvatten. Den senare faktorn kan utvecklas genom att nya installationer införs där även mindre sådana troligtvis skulle ge en betydande skillnad. Andra metoder för att minska vattenfotavtrycket ligger i att generera en högre skörd per hektar land.

Nyckelord: Vattenfotavtryck, konsekvensanalys, vattenanvändning, vattenkonsumtion, vattenförorening, Nicaragua, kaffe

Institutionen för Geovetenskaper, Luft-, vatten- och landskapslära, Uppsala Universitet. Villavägen 16 SE-752 36 Uppsala

PREFACE

This thesis is the final part of my studies at the Master Programme in Environmental and Water Engineering at Uppsala University (UU) and the Swedish University of Agricultural Science (SLU). The degree comprises 30 credits and is the result of a Minor Field Study carried out in Nicaragua during 10 weeks of the fall of 2015.

I would like to thank all who contributed to make the project possible. Firstly, the Swedish International Development Agency (Sida) for the financing of the Minor Field Study on behalf of the Working group in Tropical Ecology (ATE) at UU. Secondly, Caroline Johansson and Vänskapsförbundet Sverige – Nicaragua (VFSN) for bringing me together with the UCA Miraflor. Moreover, I would like to give my gratitude to Roger Herbert, subject reviewer from UU, and Martyn Futter, supervisor from SLU, for guidance and advice about my work.

Many thanks to Silvia González, Edwin Gutiérrez, Yoarci González, Angelika, Ramón and Francisco Muñoz for all the help as well as the guiding through the cloud forests of Miraflor and the work of UCA Miraflor. Thanks also to all the kind coffee producers I visited in Miraflor for letting me observe and participate in their work.

I would also like to express my appreciation to the Water Footprint Network for giving me permission to use figure 3.1 from *The water footprint assessment manual*: *setting the global standard* (2011) and Anne-Marie Boulay for permission to use figure 1 from the article *Complementarities of Water-Focused Life Cycle Assessment and Water Footprint Assessment* (2013).

Last but certainly not least, I would like to thank my family and friends for always supporting me and being there for me.

Emma Moberg
Uppsala, March 2016

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Vattenfotavtrycket för produktionen av kaffe i Miraflor, Nicaragua
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Vatten är en avgörande faktor för allt liv på jorden. Trots att mer än 70 % av jordens yta är täckt av vatten är mindre än 3 % av denna del färskvatten. Tillgängligheten på vattnet varierar dessutom vilket visas genom att runt 2.7 miljarder lever i områden med en påtaglig vattenbrist under minst en månad varje år. Med en förväntad ökning av jordens befolkning och ekonomisk tillväxt samt klimatförändringar spås vattenbrist och föroreningar av vatten öka och riskera att övergå till en global kris. Hanteringen av jordens vattenresurser behöver därför förbättras för att kunna garantera att rent vatten finns tillgängligt för dricksvatten, livsmedelsförsörjning och sanitetslösningar. Det är särskilt viktigt för jordbruket eftersom denna sektor står för 70 % av den totala vattenanvändningen i världen.

Som en hjälp för en mer effektiv användning av vatten finns det så kallade *vattenfotavtrycket*. Med ett vattenfotavtryck kartläggs vattenanvändningen för produktionen av en vara, för en process i en produktionskedja, ett företag eller för ett helt land. Därtill kan vattenfotavtrycket användas som ett verktyg för att bedöma miljöpåverkan av vattenanvändningen. En av de mest använda metoderna för beräkning av vattenfotavtryck utvecklades av Water Footprint Network (WFN).

Syftet med den här studien var att använda WFN:s metod för att beräkna vattenfotavtrycket för produktionen av kaffe i området Miraflor i Nicaragua. För att framställa en kopp drickfärdigt kaffe ingår en lång process för odling och bearbetning av bönorna. I processerna används vanligtvis stora mängder vatten och mycket vatten riskerar också att förorenas på grund av användningen av bekämpningsmedel och gödsel. Meningen med studien var därför att visa var förbättringar kan göras i vattenresurshanteringen för produktionen av kaffe i Miraflor, både vad gäller mängden vatten som används i de olika produktionsstegen som i behandlingen av restvattnet från kaffeproduktionen.

Studiens resultat visar att vattenfotavtrycket per ton skördat kaffe i Miraflor uppgår till 20 049 m^3 färskvatten. Sett till hela skörden för säsongen 2015/2016 ger detta ger en total konsumtion av mer än 6 000 000 m^3 vatten. Resultatet påvisar att vegetationsperioden är den i särklass största bidragande faktorn till kaffeproduktionens vattenfotavtryck med 98,1 % av det totala avtrycket. Nicaragua och regionen där Miraflor ligger har ökande problem med vattenbrist orsakat av torka och föroreningar av vattenresurser. Studiens resultat visar tillsammans med denna bakgrund att nuvarande tekniker i kaffeproduktionen i Miraflor bör förbättras för att minimera konsekvenser för lokala vattenresurser och miljön. Främst är det användningen av bekämpningsmedel och gödsel som ger upphov till det stora vattenfotavtrycket. Kaffeproduktionen orsakar även överträdelser av de bestämmelser som finns i Nicaragua om värden på vattenkvalitetsparameterar i restvatten från kaffeproduktion. En ytterligare betydande faktor för vattenfotavtrycket som påvisas i studien är konsumtionen av regnvatten via avdunstning från grödorna i fält.

För att minska vattenfotavtrycket bör i första hand en mer medveten användning av bekämpningsmedel och gödsel införas. Därtill bör det ske en förbättring i hanteringen av utsläppsvatten. Den senare faktorn kan utvecklas genom att nya installationer införs där även mindre sådana troligtvis skulle ge en betydande skillnad. Andra metoder för att minska vattenfotavtrycket ligger i att generera en högre skörd per hektar land.

TABLE OF CONTENTS

DEFINITIONS

Water use – Water is withdrawn from its source for use and later returned to the same catchment area.

Consumptive water use - Water is permanently withdrawn from its source, i.e. due to evaporation or due to incorporation into a crop or final product. It also includes the water which is returned to its source after a long time period.

Virtual water - The water embedded in the production of a good or a service.

Water footprint - A measure of the amount of water used for producing a good or a service. It includes both the direct and indirect use of water as well as the pollution of water in the production. It can also indicate the amount of water used in a specific process, in a business, a designated geographical area or an entire nation.

Water Footprint Network - Published a global standard with the Global Water Footprint Assessment in 2009.

Water footprint assessment (WFN method) – The standard by the WFN for calculating a water footprint. A full assessment includes four steps which are setting goal and scope for the study, accounting for the water footprint of the chosen object, assessing the sustainability of the accounted footprint and finally formulating a response strategy. The total water footprint includes the green, blue and grey water footprint components.

Green water footprint - Rainwater on land which has evaporated, transpired or been incorporated into plants.

Blue water footprint - Surface or groundwater resources that evaporates or is incorporated into a product. It also includes water which is withdrawn from one catchment area and returned to another or returned in another time period than the time of its withdrawal.

Grey water footprint –A theoretical volume water which refers to the demand of freshwater for the dilution of contaminated water to reach water quality standards.

ABBREVIATIONS

COD - Chemical oxygen demand

CWU - Crop water use

ET - Evapotranspiration

FAO - Food and Agriculture Organization of the United Nations

Ineter - Nicaraguan Institute for Territorial Studies (Instituto Nicaragüense de Estudios Territoriales)

ISO - International Organization for Standardization

LCA - Life cycle assessment

UCA Miraflor - Union of cooperatives of Miraflor, Nicaragua with 46 producers of coffee (*La Unión de cooperativas agropecuarias Héroes y Mártires de Miraflor).*

WF - Water footprint

WFN - Water Footprint Network

n.d. - No date

1 INTRODUCTION

Water is crucial for human existence and for life in general. Although more than 70 % of the planet is covered by water, less than 3 % is freshwater of which only a third is available to humans. The availability varies spatiotemporally and an estimated 2.7 billion live in areas where there is a severe shortage of water during at least one month of the year (WWF, 2015). With population and economic growth and climate change, water shortages as well as pollution are foreseen to increase and become a global crisis (The World Economic Forum, 2015). Consequently, the management of water resources needs to be improved in order to guarantee safe access to drinking water, food supply and sanitation services (The World Bank, 2015).

People use water for drinking and in domestic activities for hygiene and sanitation (The World Bank, 2015). Nonetheless, the largest water withdrawals are linked to agricultural practices. The agriculture sector is responsible for 70 % of the global water withdrawals and concurrently with the increase of the world population, there will also be an increase in water withdrawals for agriculture (Koehler, 2008; The World Bank, 2015). Pressure on water supplies is further exacerbated by cultivating water-thirsty crops in water-scarce environments. If these agricultural crops later are exported to destinations with an abundance of water, there is actually an export of water from the water-scarce regions. This was highlighted by Professor Tony Allan who stated that the problems of water shortage in the Middle East could be improved by relying more on the import of products with a high demand of water from countries with a surplus of water (Allan, 1998). Allan instituted the concept of *virtual water* which identifies the water embedded in the production of a good or a service. The virtual water concept later evolved and was followed by the term *water footprint* by Professor Arjen Hoekstra (Water Footprint Network, n.d. a).

The water footprint is a tool for mapping the direct and indirect water use for a good or a service, an activity in a bigger process chain, a business or a multi-national company. It can also be used for a designated geographical area such as for a single river basin, a municipality or even for an entire nation (Hoekstra et al., 2011). There are several methods available for the calculation of the water footprint of which the most commonly used are the methods of the Water Footprint Network (WFN) and within the framework of Life Cycle Analysis (LCA) (Jefferies et al., 2012).

According to the calculation method of the WFN, one accounts for the volume of freshwater embedded in a product including the water required for all the different process steps, the water polluted due to the processes, and also the availability of water at the locations where the water has been withdrawn (Water Footprint Network, n.d. b). The methodology focuses on three components which are the green, blue and grey water footprints. The green water footprint refers to rainwater on land which has evaporated, transpired or been incorporated into plants. The green water footprint does not include the fraction of precipitation that becomes runoff since this part is not consumed (figure 1). The blue water footprint component consists of surface or groundwater resources that have evaporated or been incorporated into a product. It can also refer to water that is withdrawn from one catchment area and returned to another or returned in another time period than the time of its withdrawal (figure 1). Finally, the grey water footprint component is the demand of freshwater for the dilution of contaminated water to reach water quality standards. Thus, the grey water footprint is not an actual but a theoretical volume (Hoekstra et al., 2011).

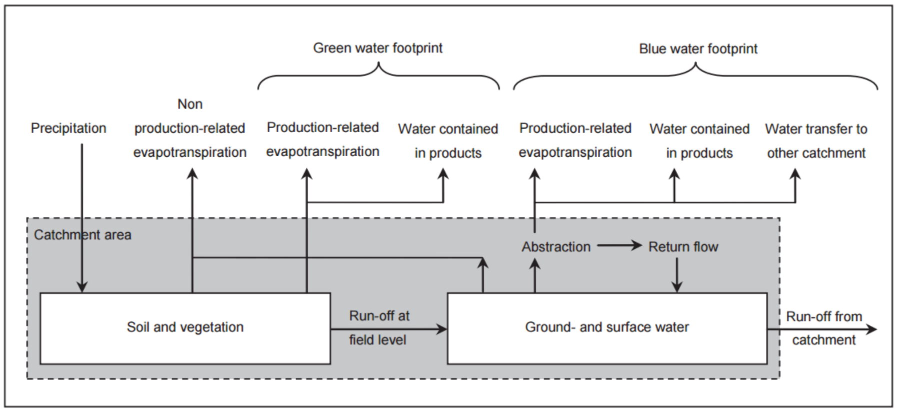


Figure 1: *The water which is included in the definitions of the green and blue water footprints (Hoekstra et al., 2011).*

This study calculates the water footprint of the production of coffee in the area of Miraflor, Nicaragua, using the WFN method. Coffee is one of the most valuable commodities in the world and around 26 million people worldwide get their income from coffee production (Global Exchange, n.d.). Behind a final cup of coffee, there is a hidden consumption of water due to the cultivation and processing of the coffee crops (Chapagain and Hoekstra, 2007). Furthermore, the production of coffee may have caused problems for both the environment and the people living in the areas around coffee plantations due to a drainage of water resources in the areas as well as contamination of water downstream the plantations (Adams and Ghaly, 2006; Padmapriya, Tharian, and Thirunalasundari, 2013).

At the coffee plantations in Miraflor, Nicaragua, there is a need for a better understanding of where and how water is being used, together with the volumes of water being withdrawn. Furthermore, it is of great importance to investigate if water gets contaminated during the coffee production in order to minimize the impacts on the environment as well as on the people living downstream of the coffee plantations. Also, it is equally important to analyze whether the production affects the availability of water in the area of and around the coffee plantations.

1.1 OBJECTIVE

The objective of the study is to determine the water footprint of coffee production in Miraflor, Nicaragua. This is done in order to examine the impact from the coffee production on local water resources and the local environment as well as the possible consequences of these factors for the people living downstream the plantations. The study aims to highlight where improvements can be made regarding water resources management, both with respect to the quantity of the water appropriated in the different process steps, as well as to the treatment of the wastewater from the coffee production.

1.2 RESEARCH QUESTIONS

The research questions of the study are as follows:

- How is the production of coffee carried out today in Miraflor and in which process steps is there an appropriation of water?
- How much water is consumed in the different process steps? *(Water consumption is defined in section 2.1.1.)*
- Where does this water originate from - precipitation or from surface, soil and groundwater resources?
- How does the production of coffee contribute to the water quality of the water recipients downstream from the plantations?
- What are the effects, if any, of the water quality problems on the local environment and the people living downstream from the plantations?

1.3 DELIMITATIONS

The following delimitations are taken into consideration in the research:

- The study only accounts for the water footprint of the production of coffee carried out in the Miraflor area. Consequently, the further processing of the coffee after leaving Miraflor is not included in the study. A full system model of the coffee production in Miraflor is shown in chapter 2.3.
- No accounting is made of the water used or consumed by the farmers in Miraflor for drinking or domestic activities such as cooking, hygiene or sanitation. The study also not accounts for the indirect water used or consumed in the supply chain of the manufacturing of machines or tools used in the coffee production.
- Another factor which is excluded from the accounting is the transport within the production carried out in Miraflor. This factor is assumed as a minor contributor to the overall footprint since the majority of the transportation is carried out by foot or by horse. The use of vehicles is mainly seen in the ultimate shipping of the coffee, hence when leaving Miraflor.

- Due to a limited budget, only a limited number of water quality variables are analyzed as an indicator of water pollution (grey water footprint), but these variables are assumed to have biggest influence on water quality.
- The study is based upon the estimated yield of coffee from the season 2015/2016.

2 BACKGROUND AND THEORY

This chapter is divided into five main parts. The first section covers information regarding the water footprint as a concept and calculation tool. In the second section, the area of study is presented. This is followed by an explanation about how the production of coffee is carried out in the area of study and how this relates to water appropriation. In the fourth section, the possible impacts from coffee production on the environment and human health are discussed. Finally, a summary is presented of earlier studies of the water footprint of coffee production.

2.1 WATER FOOTPRINT

Since the concept of the water footprint was introduced in 2002 it has been further developed. There are now a number of different volume-based methods for calculating a water footprint. The Water Footprint Network (WFN) has led this development, being the first to publish a global standard with the Global Water Footprint Assessment in 2009 (Hoekstra et al., 2011).

The tools for calculating the water footprint differ in many ways and mainly in how they address water use. While the WFN uses the term *consumptive water use*, other methods may address the broader *water use*. Yet another factor separating the methods is whether they choose to include the degradation of water quality due to pollution. In the methodology developed by the WFN there is a consideration of this parameter while others exclude it. Besides the now widely-accepted methodology of the WFN, the most frequently used method for calculations of water footprint is within the framework of Life Cycle Assessment (LCA) (Jefferies et al., 2012).

2.1.1 The WFN method

The WFN methodology addresses the term *consumptive water use* which is defined according to the following cases in the global standard (Hoekstra et al., 2011):

1. Water evaporates.
2. Water is incorporated into a product.
3. Water does not return to the same catchment area from where it has been withdrawn.
4. Water does not return to a catchment area in the same period as the time of its withdrawal.

The WFN method thus distinguishes between water which is withdrawn for use and later returned and consumptive water use which refers to a permanent withdrawal due to one of the reasons in points 1-4. Consumed water is therefore no longer available for use at its source (Hoekstra et al., 2011).

A full water footprint assessment according to the WFN includes the following four steps (Hoekstra et al., 2011):

1. Setting goal and scope for the study.
2. Accounting for the water footprint of the chosen object.
3. Assessing the sustainability of the accounted water footprint.
4. Formulating a water footprint response.

The authors point out that rather than a strict directive, the steps may serve more as a guideline to the study. Consequently, one may choose which phases to include (Hoekstra et al., 2011). The steps in the water footprint assessment are described below.

1. Setting goals and scope for the study

Depending on the ultimate target of the water footprint study, the goal and the scope will vary. The purpose may be raising awareness to consumers about how the products or goods they buy affect the local scarcity of water in the production area. The consumer can thus understand where freshwater resources are being consumed or polluted and use that to choose the product with the most sustainable water management. The water footprint may also be used by companies to show where in the chain of activities there is water dependence and where improvements can be made regarding water savings or efficiency (Hoekstra et al., 2011).

Contingent upon the purpose, important factors to consider will be the level of detail and the time period to include in the study. For some water footprint studies it may be sufficient with estimates while others may require a greater level of detail to be useful. Regarding the aspect of time, one may want to show a trend analysis or simply the water footprint for one particular year. Another important factor to consider is the inventory boundaries of the study, i.e. the relevant process steps that should be accounted for in the activities of making a product. The general rule is to include all processes that substantially contribute to the total water footprint which is decided according to the level of detail in the study (Hoekstra et al., 2011).

2. Accounting of the water footprint

The water footprint contains three components which are the green, blue and grey water footprints. While the components of the green and the blue water footprints represent a consumption of water, the grey refers to a degradation of water quality due to pollution.

The three components of the water footprint give a volumetric measure of the consumption as well as the pollution of water. But to get a grip on how the water consumption and pollution impact on the environment and other aspects, it is necessary to account for the vulnerability of the water sources in the area as well as analyze how water is appropriated for other users such as individuals or industries. This is possible through the third phase of the Water Footprint Assessment which is the sustainability assessment (Hoekstra et al., 2011).

3. Sustainability assessment of the water footprint
The objective of the sustainability assessment varies depending on the perspective of the study and the level of detail is chosen depending on the goal and scope of the study. For a full assessment one considers if the water use and the degradation of water quality due to pollution fulfill with environmental, social and economical aspects (Hoekstra et al., 2011).

When assessing the environmental sustainability in the method according to the WFN, the aim is to identify whether the consumptive water use exceeds the available freshwater resources. If a certain area has an environmental hotspot it shows that there is some kind of conflict or problem with scarcity or pollution of water. In the social assessment, there is a consideration of whether the water sources are equitably allocated between users and sectors. Finally, in the economic sustainability assessment, one considers if the water use is resource efficient or whether there could be an improvement in the practice or technology used in the production (Hoekstra et al., 2011).

4. Response formulation
With the information from the accounting and sustainability assessment of the study, it is possible to formulate response strategies to reduce the water footprint and hence contributing to a more sustainable management of the water (Hoekstra et al., 2011).

2.1.2 LCA framework for assessing water footprint

The aim of LCA studies is to give a comprehensive insight of the overall impact on the environment that can be associated with a product, a process or a company over its life time. The results of an LCA can be used to a number of purposes such as for identification of hotspots in the production chain, comparison between different products or production methods or as a base in decision-making processes (Klöpffer and Grahl, 2014).The methodology of an LCA has been standardized by the International Organization for Standardization (ISO) by the 14040 and 14044 standards (ISO 14040:2006; ISO 14044:2006). According to the 14040 standard, an LCA should include four phases which are Goal and Scope Definition, the Life Cycle Inventory Analysis (LCI), the Life Cycle Impact Assessment (LCIA) and the Interpretation phase (Klöpffer and Grahl, 2014).

In the first phase when defining the goal and scope, the intention is to include the reasons for carrying out the study and address the designed audience as well as the application of the study. The boundaries of the system are set and the most suitable model is chosen. In the LCI phase, data is collected about the resources (inputs) and emissions (outputs) over the whole life cycle of the item of importance. When performing the LCIA phase, the data compiled in the LCI is summarized in pre-destined impact categories such as global warming, eutrophication, acidification, eco toxicity and water footprint. Throughout the whole process, interpretation is carried out of the results in relation to the goal and scope (Klöpffer and Grahl, 2014).

There has been little attention in addressing freshwater use in LCA methodology as well as a lack of approaches to evaluate the impacts associated with the use (Koehler, 2008). The assessments have thus not accounted for the water footprint in the same way as the WFN method in the using of impact factors concerning loss in quality and availability of freshwater (Bayart et al., 2010). Improvement has been made to extend the LCA studies to assess the impacts on water resource use and several models have been developed. In 2014, the ISO introduced the 14046 standard which specifies how to conduct a water footprint assessment based on the principles of life cycle assessment. It is possible to carry out a water footprint assessment alone but it is more common to include it as a part of a broader environmental assessment, i.e. as one of several impact categories in a full LCA (ISO 14046:2014).

2.1.3 Comparison between WFN and LCA methodology

Both the WFN and LCA intend to serve as tools for helping the preservation of water resources. Among the similarities in the methodologies is the framework of four phases which is schematized in figure 2. Both use quantitative indicators but in different phases of the study. The WFA methodology makes the quantification in the inventory phase (i.e. The Water Footprint Accounting) using the green, blue and grey components as water use indicators. In comparison, the LCA addresses the quantitative indicators in the assessment phase (i.e. the LCIA) where the water footprint is one of the indicators (Boulay, Hoekstra and Vionnet, 2013).

With the recent water footprint standard, both the WFN and the LCA community aim to separate water use from consumption by stating the form of water use as evaporation, transpiration or product incorporation. Furthermore, both also take water scarcity in consideration with the location and time of use. However, as the ISO standard is fairly new, databases for the LCA studies are yet to be updated according to the new guidelines. With new data available, the aim is to make it possible to use the water footprint according to the methodology of the WFN as a part of LCA studies (Hoekstra et al., 2011). As for the current situation, the results may differ depending on the methodology chosen for a water footprint analysis.

In the LCA methodology, it is possible to use weighting as the ultimate stage in the impact assessment according to the guidelines of the ISO 14044:2006. In the weighting, several impact categories are put together and translated into the same scale (Klöppfer and Grahl, 2014). However, when using the methodology by the WFN, the authors recommend other methods for the assessment of the calculated water footprint since they consider the level of subjectivity too high as well as that information is lost when using weighting (Hoekstra et al., 2011).

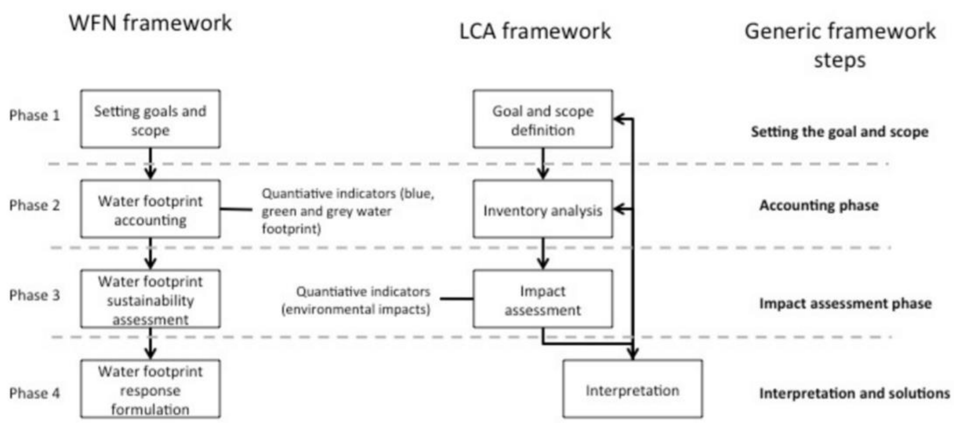


Figure 2: *The relation between the WFN and LCA frameworks with an illustration of the similarities of the phases and the difference in the quantitative indicators (Boulay, Hoekstra and Vionnet, 2013).*

2.2 AREA OF STUDY

Nicaragua is the largest country in Central America, about a third of the size of Sweden, and borders on the Pacific Ocean in the west and the Caribbean Sea/the Atlantic Ocean in the east (figure 3). The country is one of the poorest in the western hemisphere and has an economy based primarily on agriculture and forestry. Coffee is an important export and about 15 % of the export origin from coffee production (International Coffee Organization, 2014; Observatory of Economic Complexity, 2014). The majority of the coffee plantations are located in the mountain areas in the north (Landguiden, 2012). One of these cultivation areas is situated in Miraflor about 180 km north of the capital Managua (figure 3).

In Miraflor, several small scale farmers operate and grow different crops such as cabbage, beans, corn, potato and coffee. In order to facilitate the vending of their products, the farmers are members of the union of cooperatives UCA Miraflor, or *La Unión de cooperativas agropecuarias Héroes y Mártires de Miraflor.* The UCA started up the organization in 1990 and now involves in total 12 smaller cooperatives with 46 producers of coffee. The whole area of Miraflor consists of approximately 250 000 hectare of land and is divided into several altitude zones ranging from 900 to 1600 meters above sea level. The total area of production of coffee in Miraflor is 148.5 *manzanas* which is about 104 hectare of land (González, 2015; UCA Miraflor, 2015).

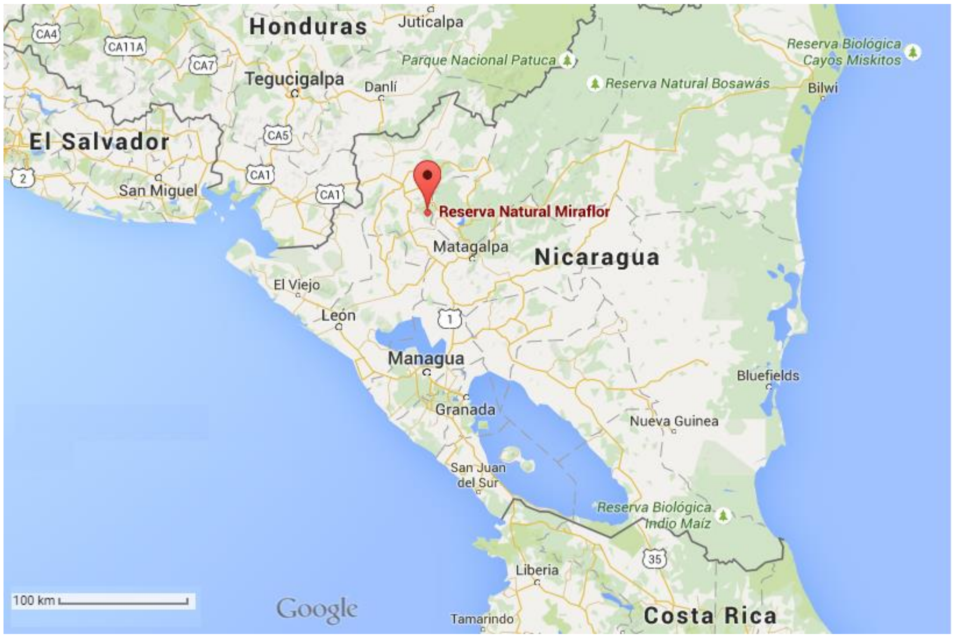


Figure 3*: Map of Nicaragua and the location of Reserva Natural Miraflor (Google Maps, 2015).*

2.2.1 The climate in the Miraflor region

The climate in the Miraflor region is tropical and has seasonal variations with a rainy period from May to the end of October followed by a dry season from the beginning of November to the end of April. The average monthly minimum and maximum temperatures as well as precipitation are shown in figure 4 and 5. The average annual temperature and average annual precipitation are 25.7 ℃ and 73.4 mm respectively (Ineter, 2015).

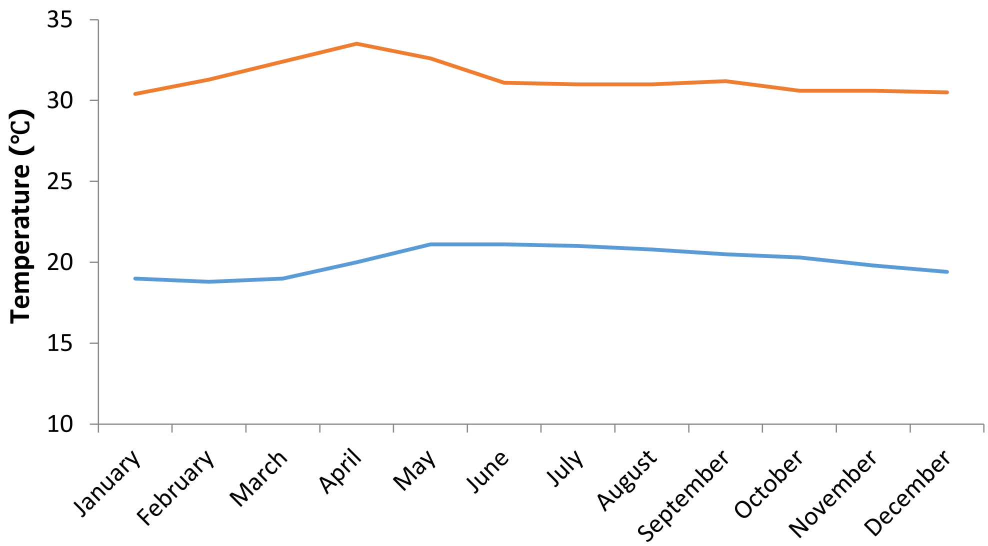


Figure 4: *Average monthly temperature minimum (blue line) and maximum (red line) in the Miraflor region. The data is based on climate data from 1983 to 2013 from San Isidro, 60 km from Miraflor (Ineter, 2015).*

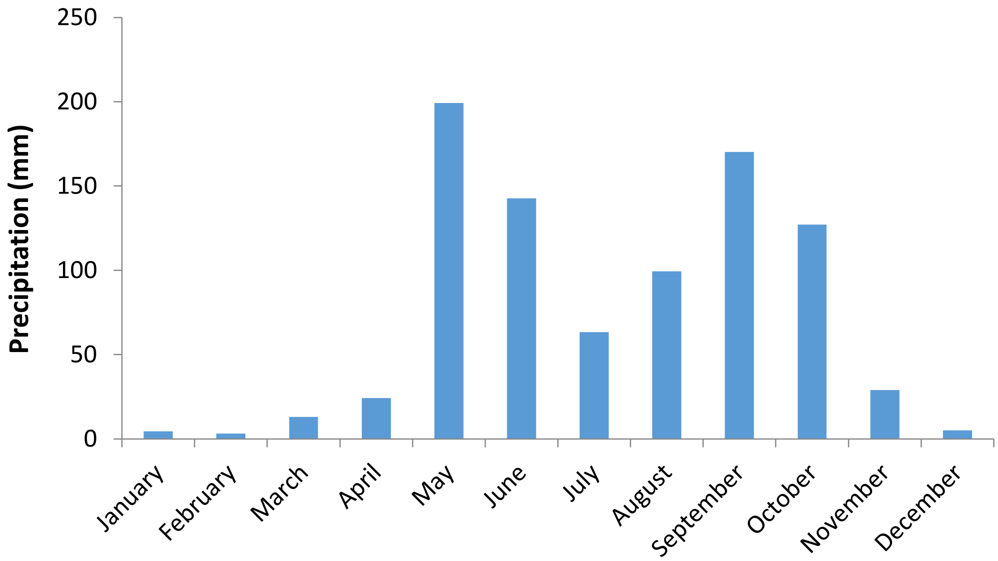


Figure 5: *Average monthly precipitation in the area where Miraflor is located. The data is based on climate data from 1970 to 1988 from Estelí, 30 km from Miraflor (The World Bank, 2012).*

2.3 THE PRODUCTION OF COFFEE IN MIRAFLOR

The coffee grown in Miraflor is of the *Coffea Arabica* species, a plant typically found in tropical high altitude areas such as Miraflor. The Arabica coffee was first cultivated in Ethiopia and Yemen and later spread to other parts of the world during the time of colonization in the 17th century. Today, people all over the world drink coffee and the Arabica bean accounts for about 75-80 % of the total production of coffee in the world (Martinez-Torres, 2006; Wintgens, 2004).

Coffee plants are perennial and can be productive for more than 80 years (Wintgens, 2004). However, the crops in Miraflor are generally only between 5 and 6 years of age (González, 2015; Hernández, 2015; Muñoz, 2015). This is due to a fungal parasite disease known as *la roya* (coffee rust), which afflicted the coffee plants in the season of 2010/2011, whereafter many plants had to be cut down (Muñoz, 2015). Before the impact of the coffee rust, the majority of the producers ran the cultivations organically without pesticides or conventional fertilizers. Notwithstanding, many of the farmers saw themselves forced to abandon the organic techniques in order to manage the disease. Fertilizers are added today, where the ones of concern consist of urea, wheat straw ash and manure as well as recycled coffee skin from pulped coffee fruits (table 1) (González, 2015, González, M.M., 2015; Gutiérrez, 2015; Hernández, 2015).

Table 1: *Fertilizers and pesticides used in the cultivation of coffee in Miraflor (González, 2015; González, M.M., 2015; Gutiérrez, 2015; Hernández, 2015).*

Fertilizers of concern	Pesticides of concern
Urea	Carbendazim
Ash (wheat straw)	Hexaconazole
Manure	Timorex Gold (organic tea tree extract)
Recycled coffee skin (pulp)	

2.3.1 The early stages in the coffee cultivation

The life of coffee crops begins with the cultivation of beans in nurseries where they eventually grow to small trees. At first, a couple of months after planting, sprouts come out and the plants start to grow up from the soil with the coffee bean on top. After some additional months, the coffee plants can be put out on the field where they proceed to grow (Martinez-Torres, 2006). In Miraflor, all the coffee plants grow shaded with the protection from trees, usually the larger banana trees (*plantains*), see figure 6 (González, 2015; Muñoz, 2015). This helps the plants to grow in a stress-free environment and saves irrigation water as it can be fed from rainwater. Other benefit from this is its help to maintain soil fertility by providing nutrients to the coffee crop (Martinez-Torres, 2006).

Figure 6: *The banana trees (plantains) giving shade to the coffee plants in the area of Los Prendedizos, Miraflor (Moberg, 2015).*

2.3.2 The blooming and harvesting of the coffee

When the plants are 3 to 4 years of age they bloom whereupon the flowers transform into coffee cherries. The cherries can be harvested after about 40 weeks (González, 2015). The harvest season occurs once a year in Miraflor, usually from the end of November until March. During recent seasons, the initiation of the harvest has been delayed to the middle of December due to the severe problems of drought in the region (González, 2015; Muñoz 2015).

2.3.3 Processing of the coffee

When the cherries have been picked they undergo several process steps in the so called *wet production method*. The coffee cherries have several layers which have to be removed in order to make the coffee ready to be shipped off for further processing and roasting. The anatomy of the coffee cherry with its different layers is shown in figure 7. The processing steps in Miraflor include the removal of the *pulp* and the *mucilage* (González, 2015; Gutiérrez, 2015; Hernández, 2015; Muñoz, 2015). The production of coffee in Miraflor including the processing is illustrated in the flow chart in figure 8.

The same day after being picked, the cherries are transferred to processing plants where they are inserted into a *depulper* machine to remove the pulp, i.e. the outer skin. After the depulping, the cherry is left to ferment in a tank for about 48 hours covered with the water residues from the pulping procedure. The fermentation occurs when the mucilage, i.e. the natural syrup of sugar that covers the seeds, gets in contact with the water and starts to dissolve. Afterwards, the cherry is washed with freshwater from pipes in washing channels in order to remove the residues of the mucilage. When pulp and mucilage have been removed, the remains are called *wet parchment coffee* which is later naturally dried in the sun. Once dried, the *dry parchment coffee* is stored in bags before being transported to other sites for roasting and shipping (González, 2015; Gutiérrez, 2015; Hernández, 2015).

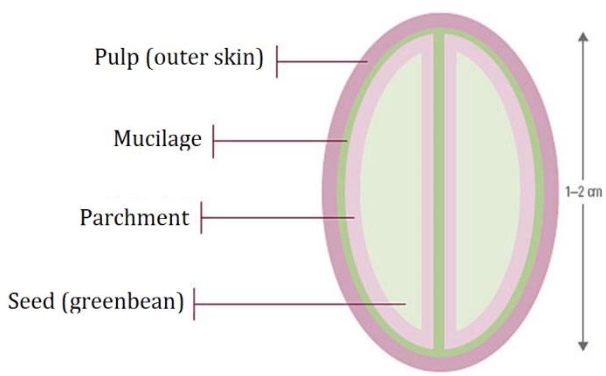


Figure 7: *The anatomy of the coffee fruit with the different layers of the cherry. Modification by Moberg (2016) from illustrations in Chapagain and Hoekstra (2003) and Greenbean (n.d.).*

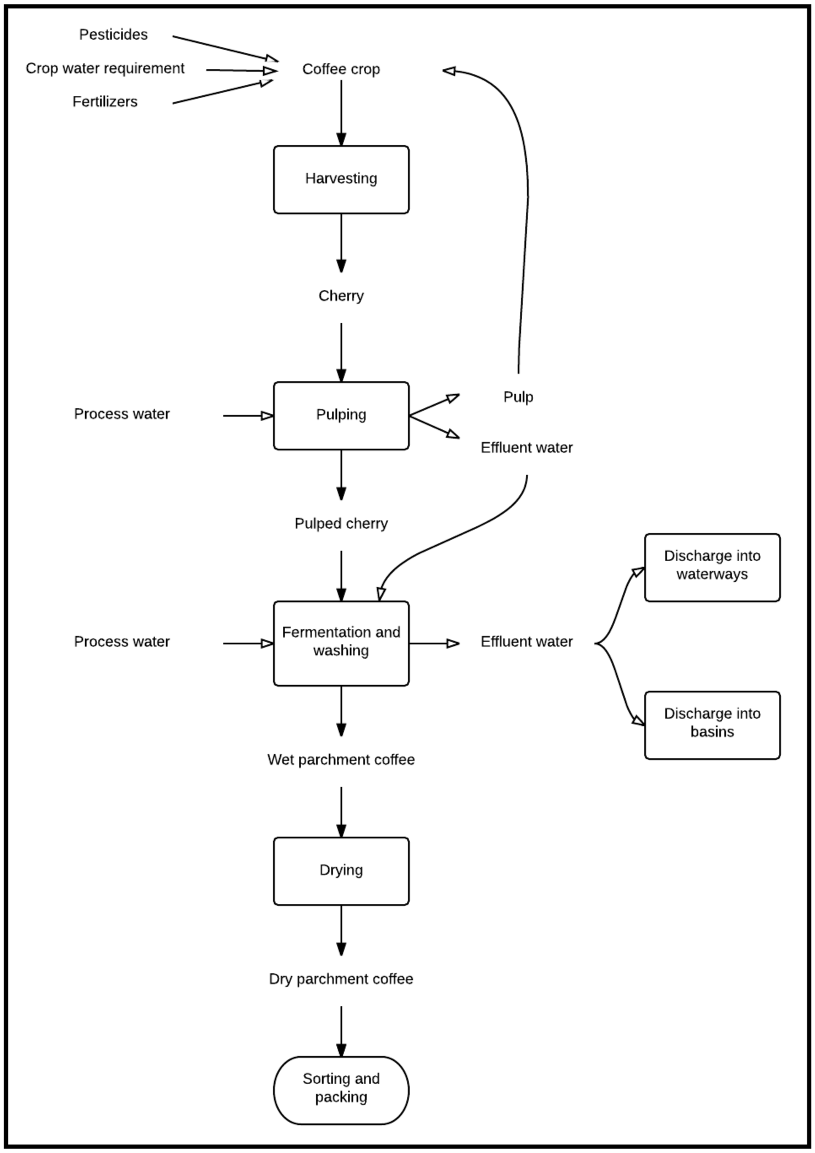


Figure 8: *System model of the coffee production in Miraflor with all the process steps, intermediate products as well as the inputs and outputs.*

2.3.4 Water use and handling of wastewater in the cultivation and processing

The crop water requirement in Miraflor is satisfied exclusively with rainwater and hence, no additional water is consumed for irrigation. Regarding the processing, i.e. the pulping, fermentation and washing, the water originates from soil and groundwater upgradient from the plantations and is brought to the processing plants in pipes.

Generally, all producers use the same techniques in their practices except from the handling of the wastewater. At about half of the processing plants, the effluent water from the pulping, fermentation and washing is led directly from the water channels straight into the waterways. The other half of the producers lead the effluent water into basins where the water is left to evaporate or percolate into the soil (González, 2015; Gutiérrez, 2015; Gutiérrez, E., 2015; Hernández, 2015).

2.4 COFFEE WASTEWATER – POSSIBLE IMPACTS ON THE ENVIRONMENT AND HUMAN HEALTH

Effluent water from the processing of coffee has a high viscosity due to its content of organic matter such as proteins, pectin and sugar from the pulp and the mucilage. The viscosity of the water has led to it being referred to as *honey water*. When the mucilage starts to dissolve during the fermentation process, the sugars are converted into organic and acetic acids which impact the acidity of the wastewater, lowering the pH-values to around 3.5 to 4.5 (Adams and Ghaly, 2006; Padmapriya, Tharian and Thirunalasundari, 2013). If the effluents are discharged directly into rivers and streams without any kind of treatment, there is a risk that the pH in the receiving water bodies will be affected to substantially lower levels than the natural values of about 6.5 to 7.5 (Beyene et al., 2012; Lampert and Sommer, 2007). If the pH would be reduced to lower than 5 for a longer time, the lives of most aquatic animals are jeopardized (Lampert and Sommer, 2007).

When microorganisms in the receiving bodies of water are provided with the organic matter in the effluents, they will start decomposing it. Decomposition in presence of oxygen will release ammonium which later transform into nitrate by the microorganisms in a so called *nitrification* process. The transformation only occur in aerobic conditions, i.e., in presence of oxygen where the nitrate works as nutrition source for the organisms. A general measure of the capacity of microorganisms to decompose organic matter is the *chemical oxygen demand* (COD). This parameter indicates the amount of oxygen required in the oxidation of organic matter. Concerning coffee effluents, the COD may be considerably higher than the natural levels of the water bodies which may cause depletion of the oxygen levels in the water. This may cause *anoxic* conditions in which the bacteria, in absence of oxygen, start to oxidize the organic compounds, using nitrate as electron acceptor in the oxidation process called *denitrification*. Furthermore, ammonium or nitrate will be released depending on the working microorganism. The process where ammonium is released is called *ammonification* while the release of nitrate is called *nitrification* (Lampert and Sommer, 2007). Bacteria living in anoxic environments may start reducing sulfate in the further decomposition which will produce hydrogen sulfide (H_2S). Hydrogen sulfide is toxic to the biota and may also cause a bad and rotten smell (Bydén, Larsson and Olsson, 2003).

According to a study by Haddis and Devi (2008) about coffee wastewater problems, the anoxic conditions in the waters may cause health issues for humans in the vicinity of the processing plants who use the water for domestic purposes. Haddis and Devi highlight the increased ammonium concentrations in the waters as a contributing factor to eye and skin irritation, stomach problems and respiratory issues.

Another outcome linked to the wastewater being led into the waterways is the increase of the turbidity of the water with a darker color which is due to the high amount of suspended and non-dissolved solids as well as the red color of flavonoids from the coffee cherry. Besides the organic matter, the suspended particles may consist of the increased number microorganisms (Adams and Ghaly, 2006; Padmapriya, Tharian and Thirunalasundari, 2013). With more suspended particles and higher turbidity, more heat may be absorbed from sunlight, thus heating the water. This may decrease the levels of oxygen even more since oxygen dissolves better in colder water. Moreover, the photosynthetic activity may be reduced due to the suspended particles which scatter the sunlight. With a decrease in the photosynthetic rates, even less oxygen levels will be available and aquatic life may be threatened (Lampert and Sommer, 2007).

2.5 EARLIER STUDIES OF THE WATER FOOTPRINT OF COFFEE PRODUCTION

Earlier studies have been performed of the water footprint of coffee within the LCA framework (Coltro et al., 2006; Humbert et al., 2009). Moreover, Mekonnen and Hoekstra (2011) covered the area with reports on the global average water footprint of coffee. Chapagain and Hoekstra (2003; 2007) have performed studies on the virtual water content in a regular cup of coffee in the Netherlands. However, there have been no findings of more local studies using the complete methodology of the Water Footprint Network i.e. separating the green, blue and grey water footprints.

Mekonnen and Hoekstra (2011) state that the global average water footprint of coffee amounts to 15 774 m^3/ton of processed coffee which has been rain-fed in the cultivation. This total footprint consist of the green water component of 15 251 m^3/ton and the grey water component of 523 m^3/ton while the blue water footprint equals zero.

According to Coltro et al. (2006), the production of 1 ton of processed coffee in Brazil requires about 11.4 ton of water whereas it produces between 3 and 8.5 ton of wastewater. Humbert et al. (2009) state that a 1 dl cup of processed and roasted coffee requires between 2.5 and 4 liters of water when focusing on rain-fed crops. A third of the volume relates to the use in the cultivation and processing. In case of accounting for the water use when considering cultivations which are irrigated, the scenario changes substantially to a water footprint of 130 liters per cup. This value is closer to the results of Chapagain and Hoekstra (2007) who state that 140 liters of water are embedded in a standard cup (1.25 dl) of coffee of which the largest volumes are linked with the cultivation of the crops. According to the study, the processing water use accounts for only 0.34 % of the water consumed when growing the crop. While the authors include the locations where the crops have been grown, they exclude the evaluation of whether these areas suffer from water scarcity.

3 MATERIAL AND METHODS

This study follows the methodology for evaluating the water footprint according to the standard developed by the Water Footprint Network (WFN). Since no other study has been found using the full methodology by the WFN in the chosen field of study, it is considered as particularly interesting.

The chapter is divided into two main parts:

- Firstly, the methodology of accounting for the water footprint is addressed. This section separates the methodology of how to account for the water footprint of growing the crop and the accounting of processing the harvested coffee.
- Secondly, the procedure of the sustainability assessment is explained.

3.1 ACCOUNTING FOR THE WATER FOOTPRINT

In order to account for the water footprint of the coffee production in Miraflor, mapping of the different process steps in the coffee production was made to see where and how the water is being appropriated as well as how the agricultural practices are managed. To accomplish this, a literature study was carried out about coffee production. Furthermore, a complementary dialogue was held with the managers of the UCA Miraflor and several of the farmers in Miraflor to know more about the processes and their agricultural practices (González, 2015; González, M.M., 2015; Gutiérrez, 2015; Gutiérrez, E., 2015; Hernández, 2015; Muñoz, 2015). Through this information, a conceptual model was set up of the system, i.e. with the different process steps covering all the water consuming processes. The conceptual model was illustrated in chapter 2.3.

Furthermore, participation was made in the coffee processing at five of the biggest producers in Miraflor whose production provides for about 60 % of the total yield of coffee in Miraflor. Four of the producers carry out their production at the area of *Los Prendedizos* (map in appendix I). Here, the effluent water from the process plants is released into the waterways downstream the area. The fifth producer included in the study manages a plantation in the area of *Apagüis/El Terrero* (map in appendix I). At this site, the wastewater is led into an evaporation/percolation basin.

From now on, the production in the Los Prendedizos area will be referred to as “Site 1” while the one in Apagüis/El Terrero will be referred to as “Site 2”.

3.1.1 The water footprint of growing a crop

The water footprint of growing a crop equals the sum of the green, blue and grey water footprint components.

3.1.1.1 The green and blue water footprint of growing a crop

The green and blue water footprint components (WF_{green} and WF_{blue}, in m^3/ton of harvested coffee) of growing a crop are defined as the crop water use (CWU_{green} and CWU_{blue}, in m^3/ha of arable land) divided by the crop yield (ton/ha arable land), as shown in equations 1 and 2. Additionally, one has to account for the fact that water is incorporated into the harvested crop to get the total water footprint of the crop farming (Hoekstra et al., 2011).

$$WF_{green} = \frac{CWU_{green}}{Yield} \quad (1)$$

$$WF_{blue} = \frac{CWU_{blue}}{Yield} \quad (2)$$

The green and blue crop water use consists of the total amount of rainwater and irrigation water - that evaporates from the field during the growing period - respectively. This allows for an estimation of the total water consumption distributed over the total annual or seasonal yield.

The crop water use of each of the components is calculated as the accumulation of the daily evapotranspiration (ET, in mm) of the whole period from when the crop is planted (day 1, d=1) to the harvest (length of growing period in days, lgp) (equations 3 and 4). In order to show the crop water use as a water volume per land surface (i.e., in m^3/ha) one has to convert the water depth (in mm) by multiplying the accumulation with a factor 10 (Hoekstra et al., 2011).

$$CWU_{green} = 10 \cdot \sum_{d=1}^{lgp} ET_{green} \quad (3)$$

$$CWU_{blue} = 10 \cdot \sum_{d=1}^{lgp} ET_{blue} \quad (4)$$

To calculate the green and blue evapotranspiration (ET_{green} and ET_{blue}, in mm) it is common to use an indirect method, i.e. a model based on empirical formulas and thus estimating the potential evapotranspiration. In this study, the CROPWAT model was used through the recommendations from Hoekstra et al. (2011).

Regarding the water incorporated into the harvested crop, it is possible to deduce this fraction by simply looking at the water content of the crop. The water content can be translated into a water volume (in m^3) per ton of the harvested crop by making use of the fact that 1 m^3 (1000 liters) of water weights 1 ton (1000 kg) (Hoekstra et al., 2011).

The CROPWAT model

The CROPWAT model has been developed by the Food and Agriculture Organization of the United Nations (FAO) and is based on the Penman-Monteith equation (FAO, 2010).

In this study, the input data necessary to run the model was on climatic conditions in the area as well as characteristics of the coffee crop. The climate parameters of importance were minimum and maximum temperature, sun hours, humidity, wind speed and precipitation. All data except from precipitation was obtained through the Nicaraguan Institute for Territorial Studies (Instituto Nicaragüense de Estudios Territoriales, Ineter) and consisted of daily averages over a time period of 30 years (between 1983 and 2013) from a weather station in San Isidro, located 60 km from Miraflor. The precipitation data was obtained through The World Bank and consisted of daily averages over a time period between 1970 and 1988 from Esteli, located 30 km from Miraflor. A summary of the climate data is available in appendix II. Regarding the characteristics of the coffee crop, data was collected from Allen et al. (1998), see appendix II.

Given the climatic conditions and the coffee crop characteristics, the CROPWAT model returned the potential green and blue water evapotranspiration (ET_{green} and ET_{blue}) which could be used to estimate the crop water use (CWU_{green} and CWU_{blue}).

A brief summary of the CROPWAT model and the procedure of estimating the green evapotranspiration is available in appendix II.

3.1.1.2 The grey water footprint of growing a crop

To account for the grey water footprint component of growing the coffee crops, it was necessary to consider several factors according to the methodology of Hoekstra et al. (2011). These factors were the following ones:

1. The yield of coffee in Miraflor (in ton/ha).
2. The chemical application rate (AR, in ton/season) of fertilizers containing the parameters analyzed in the study.
3. The leaching-runoff fraction of the pollutants (α) which estimates the waste flow that reaches the freshwater bodies downstream the coffee plantations.
4. The maximum acceptable concentration of the pollutants in the receiving water bodies (c_{max}).
5. The natural concentration of the substances in the receiving water bodies (c_{nat}), i.e. the concentration that would occur if no human disturbance would have been involved.

Points 1 and 2 were given after dialogue with UCA Miraflor and the coffee producers included in the study. Regarding points 3 to 5, these are accounted for in the following sections.

Estimations of the leaching-runoff fraction of the pollutants (α)

When a chemical load is applied to the soil, a part of the pollutants will be transported away to soil and groundwater via leaching or to surface water via runoff. The movement of the chemical substances is determined by various factors such as the properties of the pollutants, climatic conditions and agricultural practices on site. The fraction that actually reaches a freshwater body is difficult to measure with a water sample since it cannot be guaranteed that the diffuse source of pollution affects the water quality (Hoekstra et al., 2011).

With a methodology developed by the WFN, it is possible to estimate the percentage of a load containing a certain pollutant that will finally reach a freshwater body i.e. the leaching-runoff fraction (α) (Franke, Boyacioglu and Hoekstra, 2013).

α is calculated as follows by equation 5 (the parameters are described below):

$$\alpha = \alpha_{min} + \frac{\sum_i s_i \cdot w_i}{\sum_i w_i} \cdot (\alpha_{max} - \alpha_{min}) \qquad (5)$$

According to the methodology, one has to consider several parameters that influence the leaching-runoff fraction and the factors differ from one substance to another. The influencing factors are weighted with 5, 10 or 15 % for the final result (w_i in equation 5). Each factor is given a score (s_i in equation 5) between 0 and 1 for the potential to leach or runoff where 0 indicates a very low potential and 1 a very high. If no information can be obtained about one factor, the authors suggest a default value of 0.5. When the score of the factors has been decided, the total leaching-runoff fraction is calculated using equation 5. The values of α_{min} and α_{max} differ depending on the substance of importance and are given by the guidelines of the WFN (Franke, Boyacioglu and Hoekstra, 2013).

In this study, the substances of interest were nitrogen and phosphorus (from the application of fertilizers into the soil) as well as the pesticides Carbendazim, Hexaconazole and Timorex Gold. The latter one is organic and was considered to be composed of natural substances and thus assumed as not harmful to the local environment in the same way as the synthetic pesticides (AgNova, n.d.; Naturskyddsföreningen, n.d.). The influencing factors of each contaminant and further calculations of the leaching-runoff-fraction including weight and score of the category are shown in appendix III.

The maximum acceptable concentration of the pollutants in the receiving water bodies (c_{max})

The parameters included in this study were pH, temperature, chemical oxygen demand (COD), total phosphorus, total nitrogen and suspended solids as well as the pesticides carbendazim and hexaconazole. Except for the pesticides, all the parameters were chosen according to previous studies addressing how the production of coffee impacts on water quality (Chanakya and Dealwis, 2004; Beyene et al., 2012). The pesticides were chosen after visiting the productions sites in Miraflor where it was stated that some of the producers apply them in their agricultural practice.

There are no standards for ambient water quality in Nicaragua. The available standards addressing water quality concerns water for human consumption (CAPRE, 1993) and restrictions about the discharge of effluent waters from industrial processes where coffee processing plants are included (Casa de Gobierno, Nicaragua, 1995). The only parameter included in our study which is addressed in the CAPRE (1993) is the total nitrogen (nitrate, nitrite, ammonium and organically bound nitrogen). In the latter, there are restrictions regarding that the pH of the effluent waters must be in the range between 6.5 and 9 while the total amount of suspended solids and the chemical oxygen demand cannot exceed 150 mg/l and 200 mg O_2/l respectively (Casa de Gobierno, Nicaragua, 1995).

When no ambient water quality standards are available, the WFN guidelines for the grey water footprint suggest using a mixture of the most updated and scientifically reliable standards (Franke, Boyacioglu and Hoekstra, 2013). In this study, the following standards were used of the maximum acceptable concentrations of the parameters included in the study (the concentrations are showed in table 2):

- The Canadian water quality guidelines for the protection of aquatic life (CCME, 2013).
- The European Commission directive on the quality of water intended for human consumption (EC, 1998).
- The European Economic Communities standards concerning the quality required of freshwater intended for abstraction of potable water (EEC, 1975).

Thus, the Nicaraguan CAPRE standard was excluded since the CCME (2013) includes the total nitrogen in the ambient water quality standards.

Table 2: *Maximum acceptable concentrations of the parameters included in the study according to CCME (2013)[1], EC (1998)[2] and EEC (1975)[3].*

Parameter	c_{max}
pH	6.5-9[1]
COD [mg O_2/l])	30[3]
Suspended solids [ml/l]	25[3]
Total nitrogen [mg/l]	13.47[1]
Total phosphorus [mg/l]	0.02[1]
Temperature [°C]	22[4]
Carbendazim [mg/l]	0.0001[2]
Hexaconazole [mg/l]	0.0001[2]

The total nitrogen refers to the sum of ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) and organically bound nitrogen which have been obtained through CCME (2013).

Water sampling for the natural concentration (c_{nat}) of the pollutants in the receiving water bodies

Since no data was available of the characteristics of the water in Miraflor, samplings and further evaluation of the water had to be carried out. Sampling was made upstream the production sites involved in the study (map of sampling sites in appendix I). The locations were chosen in order to minimize anthropogenic influence on the water quality.

To get a better understanding of where to carry out the sampling, a dialogue was conducted with UCA Miraflor as well as with a local biologist/guide of the area (Muñoz, 2015). Before taking the samples, the areas were explored by foot. The samplings were carried out both before and after the beginning of the harvest to secure an accurate value. The sampling dates were the 13th and the 20th of October as well as the 10th and 17th of December 2015. Measuring of the water and air temperature was carried out in field. Right after sampling, the water bottles were chilled in a cooler bag and transferred to the closest laboratory, located in León 160 km from Miraflor. At the laboratory, the samples were analyzed with respect to the chosen parameters except from the pesticides. The laboratory had limited resources and concentrations of the pesticides of importance could not be analyzed. Following the recommendations of the guidelines of the WFN, a natural concentration of 0 was chosen for them. This is justified by the fact that human-made chemical substances do not occur naturally in water (Franke, Boyacioglu and Hoekstra, 2013). Furthermore, since the chosen sampling sites were located far away from the cultivation areas, the risk of finding pesticides in the water was considered as low.

Calculating the grey water footprint of growing the coffee crops
The data from points 1 to 5 was later used to calculate the grey water footprint component of growing the coffee (WF_{grey}), using equation 6 below (Hoekstra et al., 2011):

$$WF_{grey} = \frac{(\alpha \cdot AR)/(c_{max} - c_{nat})}{Yield} \qquad (6)$$

As previously noted, α is the leaching-runoff fraction, *AR* the application rate (in ton of applied chemicals/season), c_{max} the maximum acceptable concentration and c_{nat} the natural concentration in the receiving water body.

The final grey water footprint component of growing a crop includes only the most critical pollutant, i.e. the pollutant that requires the highest demand of water for the dilution to reach maximum acceptable concentrations.

3.1.2 The water footprint of processing the coffee

The stages where water is consumed in the processing of the coffee beans include the pulping, fermentation and washing of the beans as previously explained in chapter 2.3. The total water footprint of these process steps are calculated according to the methodology of Hoekstra et al. (2011) and are explained in the following paragraphs.

3.1.2.1 The green water footprint of processing the coffee
The green water footprint component in a process step is the volume of rainwater consumed. It consists of the green water evaporated and incorporated in the coffee cherry during the process steps. It does not include the part of the precipitation that runs off or recharges the groundwater reserves (Hoekstra et al., 2011).

The water that is used in the processing of the crops origin from soil and groundwater and thus no green water is consumed in the process steps.

3.1.2.2 The blue water footprint of processing the coffee
The blue water footprint component in a process step is the volume of surface or groundwater consumed. This includes the water which evaporates or that is incorporated into the product. It also refers to water abstracted from one catchment but returned to another. Furthermore, it includes the water returned to the same catchment but in a different time period (Hoekstra et al., 2011).

To estimate the blue water footprint component of processing the coffee it was necessary to carry out measurements of the water consumption at the production sites in Miraflor. These were made by approximating the discharge, i.e., the volume rate of water flow that was transported per time unit through the water channels or the water pipes at the processing plants. The measurements were carried out using a vessel and a stopwatch.

3.1.2.3 The grey water footprint of processing the coffee

The grey water footprint component of a process steps equals the volume of freshwater required to dilute polluted water to concentrations that do not exceed the maximum acceptable concentrations. For the calculation of the grey water component (WF_{grey}, in m^3/ton of harvested coffee) one has to consider the load (L, in kg/s) of contaminants entering a water body in relation to the critical load (L_{crit}, in kg/s) and the runoff flow rate of the water body (Q_R, in m^3/s) as follows in equation 7 (Hoekstra et al., 2011):

$$WF_{grey} = \frac{L}{L_{crit}} \cdot Q_R \tag{7}$$

The critical load is defined as the amount of contaminants that fully will consume the capacity of assimilation of the receiving water body and is calculated as follows by equation 8 where c_{max} and c_{nat} are the maximum and the natural concentrations in the water body (Hoekstra et al., 2011).

$$L_{crit} = Q_R \cdot (c_{max} - c_{nat}) \tag{8}$$

By inserting equation 8 in 7 one gets another expression for the WF_{grey}:

$$WF_{grey} = \frac{L}{c_{max} - c_{nat}} \tag{9}$$

Depending on whether the pollution originates from a point source or a diffuse source, the load that enters the receiving water body will be different and one has to make different calculations.

Point source pollution

When handling point source pollution, the wastewater containing the pollutants is directly released into the waterways. In this case, one can calculate the load (L) by using the input data in points 1-4 in the equation 10 below (Hoekstra et al., 2011):

1) The effluent flow (Q_{effl}, in m^3/s).
2) The concentration of the pollutant in the effluent (c_{effl}, in mass/volume).
3) The water flow of the abstraction for a process (water withdrawal, Q_{abs}, in m^3/s).
4) The actual concentration of the intake water for a process (c_{act}, in mass/volume).

$$WF_{grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Q_{effl} \cdot c_{effl} - Q_{abs} \cdot c_{act}}{c_{\max} - c_{nat}} \quad (10)$$

If the effluent flow equals the abstraction flow, equation 10 can be simplified into the following equation 11 (Hoekstra et al., 2011):

$$WF_{grey} = \frac{c_{effl} - c_{act}}{c_{\max} - c_{nat}} \cdot Q_{effl} \quad (11)$$

The WF_{grey} from equation 11 is calculated for a volume of water/time (in m^3/s) which has to be converted into m^3/ton.

The effluent and abstraction flow (Q_{effl} and Q_{abs}) were considered the same. The effluent flow was approximated by measuring the rate of water flow that was transported per time unit through the channels and pipes in the process steps. This was measured with a vessel and a stopwatch.

The concentration of the pollutants in the effluent water was obtained through sampling of the water following the same routine as described previously for the grey water footprint component of growing a crop. The samplings were carried out on the 17th and 19th of December 2015 at the production site 2.

As previously mentioned, the water showing the natural concentrations in the receiving water bodies was abstracted from locations upstream the plantations. Since both of the production sites included in the study withdraw water from soil and groundwater upstream the plantations, the natural concentration (c_{nat}) and the actual concentration (c_{act}) of the intake water in the processing were considered the same.

Diffuse sources of pollution

With respect to diffuse sources of pollution, equation 12 is used in the calculations (further down).

One has to consider the leaching-runoff fraction of the pollutants (α) which was described earlier in this chapter when used to account for the grey water footprint component of growing the coffee crop. Here, the fraction α was used in equation 5 to account for the grey water footprint component in the process steps. *Appl*. stands for the amount of chemicals that are put into the soil per unit of time (Hoekstra et al., 2011).

$$WF_{grey} = \frac{L}{c_{max} - c_{nat}} = \frac{\alpha \cdot Appl}{c_{\max} - c_{nat}} \quad (12)$$

The total grey water footprint component is accounted by summing up the results of equations 11 and 12 and taking into consideration that half of the coffee farmers contribute to point source pollutions and the other half to diffuse sources of pollution.

3.2 ENVIRONMENTAL SUSTAINABILITY ASSESSMENT OF THE WATER FOOTPRINT

3.2.1 Environmental sustainability assessment of the green, blue and grey water footprint component

In order to assess for the environmental sustainability of the green water it is necessary to consider the green water availability in the area. However, since a consensus of how to estimate a correct value of the green water availability has not been reached, the authors recommend that the environmental sustainability focus on the blue and grey water footprints (Hoekstra et al., 2011).

The environmental sustainability assessment of the blue water footprint component shows the situation of water scarcity in the area. It is assessed by dividing the total blue water footprint in the area (WF_{blue}) with the blue water availability in the area (WA_{blue}) as shown in equation 13. The fraction indicates the water scarcity in the area (WS_{blue}). The blue water availability represents the difference between the natural runoff and the environmental flow requirement. According to the WFN methodology, the natural runoff is estimated by taking the actual run-off in the catchment area plus the blue water footprint (Hoekstra et al., 2011).

$$WS_{blue} = \frac{\sum WF_{blue}}{WA_{blue}} \qquad (13)$$

In the assessment of the grey water parameter one accounts for the water pollution level (WPL) which is the fraction of the grey water footprint component (WF_{grey}) and the runoff (RO) (equation 14) (Hoekstra et al., 2011).

$$WPL = \frac{WF_{grey}}{RO} \qquad (14)$$

3.2.2 Water resources and the exclusion of the assessment in this study

The Miraflor area is located within the Río Coco basin which has a total extension over 18 972 km^2 (FAO, 2008). The Río Coco basin is subdivided into nine smaller basins in which a part of the Miraflor area (including the areas where this study is carried out) belongs to the sub catchments of Río Estelí and the Cuenca del Río Coco. The Río Estelí is further divided into nine smaller river basins (PHCA, 2014) where the Miraflor region is integrated in the sub basin of la Quebrada Grande. As part of the Cuenca del Río Coco, Miraflor is integrated in the sub catchment of the Río Yalí – La Vainilla (Inifom, n.d.). The main resource of groundwater in the area of Estelí is the aquifer of the valley of Estelí with an extension of 45 m^3 (Castillo Hernández et al., 2006).

The water withdrawn for the processing of the crops in Miraflor is abstracted from soil and groundwater upstream the plantation sites. Since the Miraflor region is situated further up in the mountain areas from the city of Estelí, the water resources used in the coffee production do not origin from the aquifer of the valley of Estelí. Studies have been carried out about the water flow and runoff of the aquifer of the valley of Estelí (Corrales Pérez, 2005) but no study could be found about the water resources in the Miraflor region, i.e. one of the smaller la Quebrada Grande or Río Yalí – La Vainilla. Likewise, no studies on the conditions of runoff from the Río Estelí could be found.

To be able to conduct an assessment of the relation between the withdrawals for the coffee production to the available water resources in the area it would be necessary to hold more information about the conditions of the water sources in Miraflor or of the river of Estelí. For the current situation, no assessment according to the guidelines of the WFN is possible to carry out and the assessment is therefore excluded from the study. Instead, a qualitative assessment is carried out in order to evaluate the results of the study.

4 RESULTS

The chapter is divided into four parts addressing the results of the green, blue and grey water footprints as well as the total water footprint. The results of the water footprint components are subdivided into two parts containing the component of growing the coffee crops and the component of processing the coffee.

4.1 GREEN WATER FOOTPRINT

4.1.1 The green water footprint of growing the coffee crops

The CROPWAT model returns values of the potentil evapotranspiration for the green water (ET_{green}) based on the climate data. With the output data of the green water evapotranspiration, the crop water use was calculated as the evapotranspiration times a conversion factor 10 (using equation 3, results in figure 9). With data of the estimated yield of the harvest 2015/2016 (table 3), the green water footprint component of growing the crop could be deduced (using equation 1, results in table 4).

The moisture content of ripe coffee cherries is generally between 60 and 65 % (Wintgens, 2004). This gives an average of 0.625 m^3 of green water incorporated into each ton of harvested crop.

The total green water footprint component for growing the crop is shown in table 4. The input data for CROPWAT as well as the output results are shown in appendix II together with further calculations of the green water footprint.

Table 3: *The estimated yield of the harvest 2015/2016 in Miraflor.*

Total area [ha]	Estimated amount of coffee harvested [ton]	Estimated yield [ton/ha]
104	301.6	2.9

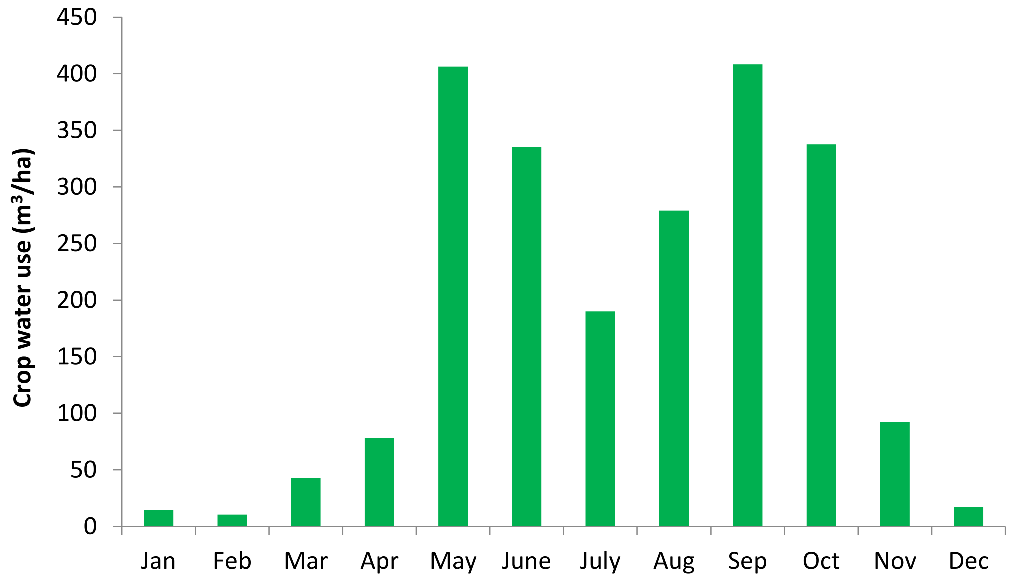


Figure 9: *The output of the CROPWAT model showing the crop water use (CWU) of green water for a year based on climate data.*

Table 4: *The total crop use of green water during an average year based on climate data, the green water consumed in the growing process as well as the volume incorporated into the harvested crops and the resulting overall green water footprint component.*

Total CWU_{green} [m^3/ha]	**Green water consumed in growing of crops [m^3/ton]**	**Green water incorporated in crops [m^3/ton]**	**Total WF_{green} of growing the crops [m^3/ton]**
6634.0	2287.6	0.625	2288.2

4.1.2 The green water footprint of processing the coffee

As explained in chapter 3.1, the water consumed in the processing of the crops originates from soil and groundwater, hence no green water is consumed in the processing steps. Consequently, the green water footprint component of processing the crops equals zero.

4.2 BLUE WATER FOOTPRINT

4.2.1 The blue water footprint of growing the coffee crops

The water requirement of the coffee crop is solely supplied by precipitation and no further irrigation is carried out. Consequently, the blue water footprint component of growing the crops equals zero.

4.2.2 The blue water footprint of processing the coffee

The blue water consumed in the processing of the coffee beans consists of the effluent water which evaporates in the evaporation/percolation basins as well as the water evaporating when the beans are left to dry in the sun. See appendix IV for calculations of the blue water footprint component.

Regarding the part of the blue water released into the evaporation/percolation basins which does not evaporate but percolates into the soil, this fraction is considered to return to the same catchment from where it was withdrawn. The same discussion is applied to the blue water discharged into the waterways downstream the plantations.

Table 5: *The total blue water footprint component of the processing consisting of the blue water consumed when evaporating from the basins as well as the drying procedure process*.

Blue water evaporated in basins [m^3/ton]	Blue water evaporated when drying [m^3/ton]	Total WF_{blue} of the processing [m^3/ton]
18.56	0.28	18.84

4.3 GREY WATER FOOTPRINT

4.3.1 The grey water footprint of growing the coffee crops

In order to calculate the grey water footprint component of growing the coffee crops it was necessary to obtain several parameters such as the leaching-runoff fractions, application rates and natural concentrations of the substances addressed in the study (see section 3.1.1.2).

4.3.1.1 Leaching-runoff fractions and application rates

The results of the leaching-runoff fractions (α) and the application rates (AR) of the substances in the fertilizers and pesticides are shown in table 6. Calculations can be found in appendix III.

Table 6: *Final values of the leaching-runoff fractions and the application rates of the substances in the fertilizers and pesticides.*

Parameter	Leaching-runoff fraction (α)	Application rate (AR) [kg/ha]
Nitrogen	0.116	168.28
Phosphorus	0.031	6.84
Carbendazim	0.056	0.36
Hexaconazole	0.051	0.13

4.3.1.2 Natural concentrations in the receiving water bodies

The sampled natural concentrations of the substances in the receiving water bodies are shown in table 7. Regarding the pesticides, the natural concentrations were chosen after the recommendations of Hoekstra et al. (2011). These are average values of the concentrations of the indicated parameters in the water downstream site 1 and 2.

Table 7: *The average values of the sampled natural concentrations downstream site 1 and 2 together with the chosen natural concentrations of the pesticides.*

Parameter	c_{nat}, site 1	c_{nat}, site 2
pH	8.19	8.38
COD [mg O_2/l]	49.16	24.72
Suspended solids [mg/l]	0.1	0.1
Total nitrogen [mg/l]	0.165	0.06
Total phosphorus [mg/l]	0.23	0.48
Temperature [℃]	19.6	20
Carbendazim [mg/l]	0	0
Hexaconazole [mg/l]	0	0

4.3.1.3 Results of the grey water footprint of growing the coffee crops

The results of the calculations of the grey water footprint of growing the coffee crops are shown in figure 10. Since the component considers a load, i.e. the applied fertilizers and pesticides, the parameters considered were nitrogen and phosphorus (from the fertilizers) and carbendazim and hexaconazole (from the pesticides).

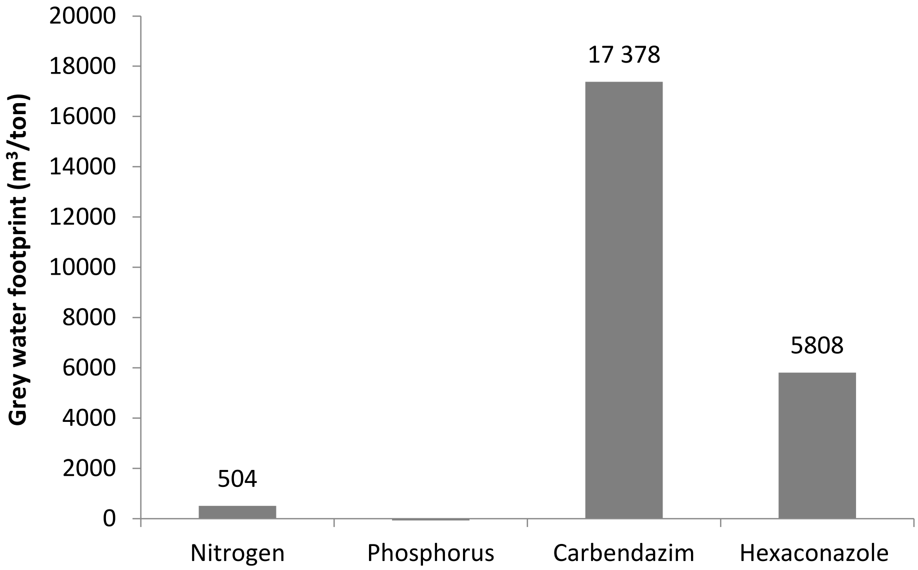


Figure 10: *The results of the calculations of the grey water footprint of growing the coffee crops with the parameters contributing to a load. The value of phosphorus is negative.*

As mentioned previously in chapter 3.1, the final grey water footprint component of each process consists of the pollutant with the highest water footprint which in this case is carbendazim with 17 378 m^3/ton.

4.3.2 The grey water footprint of processing the coffee

The contribution to the grey water footprint of processing the coffee origin from both point and diffuse sources of pollution. The contribution to the grey water footprint from point source pollutions includes the honey water which is released from the processing plants directly into the waterways. Regarding the diffuse source of pollution, it origin from the effluent water which is led from the processing plants into evaporation/percolation basins.

To account for the contribution to the grey water footprint from the pollution sources, it was necessary to know the concentrations of the selected parameters in the effluent water. The concentrations of the parameters in the effluent water could only be sampled at one location and was thus assumed to be the same in both locations. The results of the samplings of effluent water are shown in table 8. Since no analysis of the pesticides could be carried out in the laboratory, they were left out from the calculations of the grey water footprint of processing the coffee.

Table 8: *The average concentrations of the parameters in the effluent water.*

Parameter	c_{effl}
pH	5.44
COD [mg O_2/l]	1940.71
Suspended solids [mg/l]	236.0
Total nitrogen [mg/l]	0.34
Total phosphorus [mg/l]	9.85
Temperature [℃]	19.5

To account for the diffuse source of pollution, it was necessary to deduce the applied load (Appl.) of the parameters in the effluent water. The results are shown in table 9. Calculations did not consider pH or temperature since these parameters do not contribute to a load.

Table 9: *The applied load of each contaminant from the effluent water to the evaporation/percolation basins.*

Parameter	Applied load [ton]
COD	18.1
Suspended solids	2.2
Nitrogen	0.003
Phosphorus	0.092

The result of the grey water footprint component of processing the coffee is shown in table 10. The results include both the point and diffuse sources of pollution. With respect to the diffuse source of pollution, it was only possible to calculate the leaching-runoff fractions (α) for nitrogen and phosphorus.

Table 10: *The result of the grey water footprint component of processing the coffee including the point and diffuse sources of pollution.*

Parameter	Grey $WF_{point\ source}$ [m^3/ton]	Grey $WF_{diffuse\ source}$ [m^3/ton]
COD	-3845.9	-
Suspended solids	364.2	-
Nitrogen	0.8	0.32
Phosphorus	-1715.1	-72.5

The suspended solids were thus calculated as the worst pollutants with 364.2 m^3/ton.

4.4 THE TOTAL WATER FOOTPRINT OF THE COFFEE PRODUCTION IN MIRAFLOR

The total water footprint of the coffee production in Miraflor consists of the green, blue and grey water footprint components of growing and processing the coffee. The results of the total water footprint per ton of coffee are illustrated in figure 11 and the values are shown in table 11.

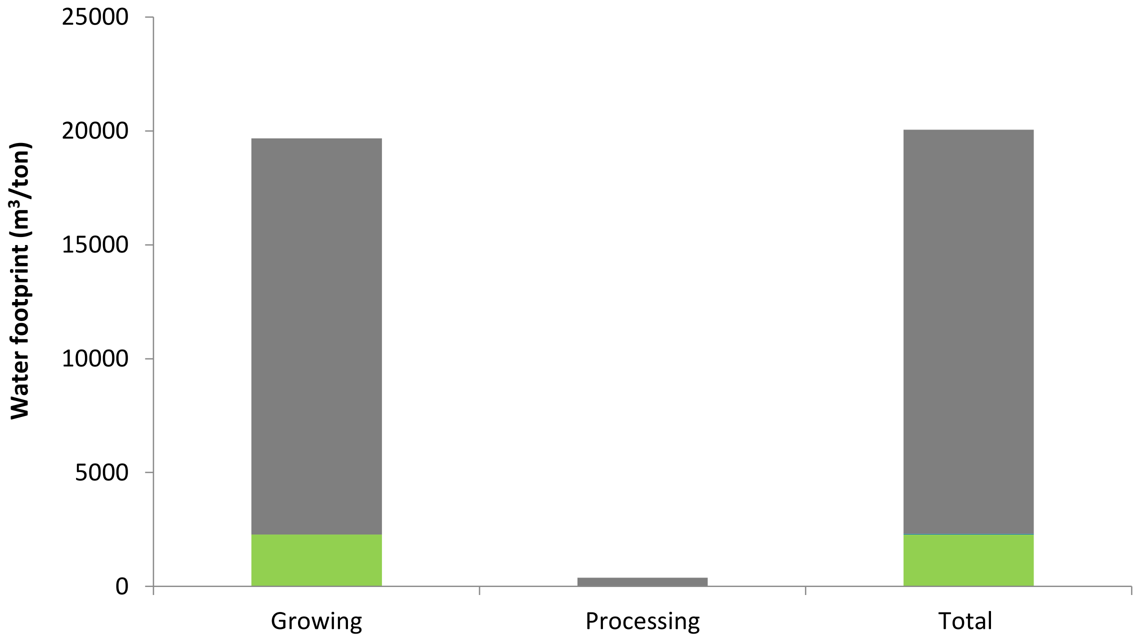


Figure 11*: The distribution of the green, blue and grey water footprint components of the growing and processing of the coffee as well as the total water footprint of the coffee production.*

Table 11: *The green, blue and grey water footprint components of the growing and processing of the coffee as well as the total water footprint of the coffee production.*

	Growing [m^3/ton]	Processing [m^3/ton]	Total [m^3/ton]
Green WF	2288.2	0	2288.2
Blue WF	0	18.84	18.84
Grey WF	17 378.5	364.2	17 741.7
Total	**19 665.7** *(98.1 % of total WF)*	**383.0** *(1.9 % of total WF)*	**20 049**

The results of the total water footprint in m^3/ton together with the estimated harvest for the season of 2015/2016 gives a total water footprint of 6 046 700 m^3/ton for the whole production of coffee in Miraflor.

5 DISCUSSION

The overall objective of the study was to account for the water footprint of the production of coffee in Miraflor, Nicaragua. This has been made using the methodology of the standard developed by the Water Footprint Network (WFN).

The final results of the total water footprint show a water footprint of 20 049 m^3 per ton of harvested coffee, where the primary contribution (88.5 %) comes from grey water footprint. This equals a consumption of more than 6 000 000 m^3 of freshwater when considering the total harvest of 2015/2016. Water is consumed both during the growing of the crops as well as in the processing of the cherries. In the growing, rainwater is consumed via evapotranspiration of the plants. Furthermore, water is polluted as a consequence of the application of fertilizers and pesticides in the cultivations, thus creating a grey water footprint. In the processing, water is abstracted from soil and groundwater upstream the cultivations. Notwithstanding, as a large part of this water later returns within the same catchment, it is not considered as consumed but simply used. Only the part of the water which is discharged into basins where it is left to evaporate is consumed according to the standard of the WFN. Moreover, the theoretical volumes of freshwater required for the dilution of the contaminants left in the basins give rise to a grey water footprint.

The results highlight the growing phase as crucial in the consumption of water with 98.1 % of the total footprint, thus leaving the processing of the coffee responsible of a smaller fraction. When analyzing the components that constitute the water footprint of the growing, it is clear that the grey water footprint is the greatest contributor with 88.3 % of the total element. This is primarily due to the application of pesticides which is carried out at about half of the cultivation areas in Miraflor. When disregarding the use of pesticides, nitrogen is the biggest contributor to the grey water footprint in the growing phase which is due to the application of fertilizers.

Next to the grey water footprint, the green water use is as an important component in the cultivation. The only consumption of blue water derives from the process step where water is discharged from the washing channels into the evaporation/percolation basins.

5.1 COMPARISON WITH EARLIER STUDIES OF THE WATER FOOTPRINT OF COFFEE PRODUCTION

The overall water footprint deduced by Mekonnen and Hoekstra (2011) of 15 774 m^3/ton coffee was smaller than the results in our study. However, the green water footprint of 15 251 m^3/ton was about six times higher than our results of 2288.2 m^3/ton. It is important to highlight the fact that the Mekonnen and Hoekstra study accounts for a global average of the water footprint disregarding location. Since the green water component relies on input data on the climatic conditions in a specific location for the CROPWAT model, a global average may be misleading since these conditions may vary from one region to another.

In the study by Chapagain and Hoekstra (2003), a global average of 2820 m^3 of virtual water per ton of harvested coffee was used when accounting for the growing phase. The study included a more local scale and the average value for Nicaragua was 3649 m^3/ton. These values are close to the green water footprint in our study of 2288.2 m^3/ton. Notwithstanding, the values from the study by Chapagain and Hoekstra (2003) did not separate green and blue water components and hence, it will not be possible to deduce whether the crops were regarded as rain-fed or irrigated and a further comparison is not possible to carry out.

With respect to the accounting for the grey water footprint, Mekonnen and Hoekstra (2011) excluded the application rates of pesticides. In fact, the only factor which was taken into consideration in the accounting for the grey water footprint was the application of nitrogen. According to the study, a consumption of 523 m^3 of freshwater was required in order to dilute the polluted water. This value is close to the one we accounted for regarding the contamination caused by nitrogen which was of 504 m^3/ton.

In order to get a better comparison of the magnitude of the findings of the grey water footprint in our study, it is necessary to use studies on the water footprint of other crops were accountings have been made with respect to both pesticides and fertilizers. The total grey water footprint in our study amounts to 5.3 million m^3 when looking at the whole production of 2015/2016. Chapagain et al. (2006) estimated the water footprint of cotton production worldwide. Their findings showed a grey water footprint of 2.1 billion m^3 per year as an average for all the producing countries. Another study by Chapagain and Hoekstra (2010) calculated the water footprint of the production of rice which showed an average grey water footprint of 4.5 billion m^3. The results of our study are thus on the small side in comparison to these findings.

When looking at the fraction between the growing and processing of the coffee, our study has similar results to the report by Chapagain and Hoekstra (2007). While their study showed that the wet production method accounted for only 0.34 % of the water consumed when growing the crop, our study finds that the production represents 1.9 % of the total water footprint. Consequently, the most crucial part in both studies is considered to be the growing phase.

In the studies performed within the LCA framework (Coltro et al., 2006; Humbert et al., 2009), the results differ considerably from ours. For instance, Humbert et al. (2009) considered rainwater as having no impact on water resources and thus excluded this factor from their calculations, giving them a final value significantly lower than our study.

Another difference was the fact that the LCA methodology, though stating that a substantial volume of water gets polluted in coffee processing, did not account for a grey water footprint. Instead, the studies used other impact categories such as water eutrophication (due to application of fertilizers) or eco toxicity (due to application of pesticides).

5.2 THE RESULTS OF THE GREEN WATER CONSUMPTION

Regarding the results of our study of the green water, the CROPWAT model was used to deduce these values. The model runs with input data on climatic conditions which will show a more accurate result the closer the meteorological station is to the actual location of the study. In our case, all data except on precipitation was taken from a station in San Isidro, about 60 km from Miraflor. The data of the average precipitation was taken from available data from Estelí, 30 km from Miraflor. The distance and the differences in altitude between the stations and Miraflor may have affected the final output of the results.

Since no detailed data on soil type in Miraflor was available from the Ineter, default values had to be chosen according to the guidelines from the FAO (2010). Furthermore, the output is based on the algorithm that the coffee crops grow under optimal conditions during the growing period which may be an overestimation of the actual situation.

According to the methodology of Hoekstra et al. (2011) one should account for the fact that coffee crops are perennial. Thus, it is necessary to account for the total crop water use for the life-time of the crops divided by the yield during the productive years. However, this was not taken into consideration in this study since the task to estimate the full life-time of the crops in Miraflor was seen as too uncertain. One of the uncertainties affecting this was the fact that the crops earlier had been affected by a fungal parasite where a majority of the crops had to be cut down and re-planted in 2010. Consequently, a theoretical value from literature was seen as too uncertain to use for estimations of the life-time of the crops. This may have affected the output results giving a lower estimate of the green water use since the coffee plant is not productive until the fifth or sixth year in field, thus requiring crop water use for the unproductive 3 to 4 years before giving a first yield.

5.3 THE RESULTS OF THE BLUE WATER FOOTPRINT

Half of the blue water which was discharged from the washing channels in the processing site and into the basins, was seen as used but not consumed. This water was considered to return within the same catchment area as from where it was withdrawn. Regarding the other half, this part of the blue water was assumed to evaporate. A crude assumption was made with respect to the fractions of the water which percolated and evaporated respectively and the actual fraction may be different in real conditions. Since no specific data on soil type was available from Ineter, a more certain result was assumed as not being possible to deduce.

5.4 THE RESULTS OF THE GREY WATER FOOTPRINT

The grey water footprint accounted for in this study corresponds to the application of pesticides and fertilizers for the season of 2015/2016. As previously mentioned, the use of pesticides and conventional fertilizer has customarily been excluded from the agricultural practices in Miraflor. However, when the cultivations were affected by the fungal parasite, many of the producers saw themselves forced to abandon the organic techniques. The trademark of the UCA Miraflor has since the start of the cooperative in the early 90s been strongly associated with the organic label and the cooperative is working on reintroducing the label for which it will be necessary to fully pass on to an organic management. Running the coffee grounds with organic agricultural practices would decrease the grey water component considerably. However, as long as fertilizers are applied, being conventional or organic, a grey water component will be seen as a consequence of the nitrogen, phosphorus or other contaminants in the substances.

Regarding the use of organic pesticides, these were not accounted for since they were assumed as having little impact on water resources. Another reason for this was the fact that there is no available data concerning the active ingredients, both regarding their leaching-runoff fractions and the water quality parameters to be used in the calculations. On one hand, organic pesticides like Timorex Gold (which is the organic pesticide used in Miraflor) are considered to be composed of natural substances such as tea tree oil (AgNova, n.d.; Naturskyddsföreningen, n.d.). However, if these are applied without care and in higher volumes and frequency than recommended, they could be potentially harmful to the local environment.

The objective of a water footprint is to allocate the results with the specific location where the study is carried out, thus reflecting the conditions in the local environment. However, since there is a lack of data sources for the maximum acceptable concentrations of the studied water bodies (and for the whole country of Nicaragua), international standards had to be used in this study.

As previously mentioned, the results of the grey water footprint according to the WFN methodology will only consist of the pollutant with the highest water footprint. The methodologies within the LCA framework normally include more impact categories linked to water use such as acidification, eutrophication and eco toxicity (e.g. Humbert et al., 2009; Coltro et al., 2006). When accounting for the theoretical volumes required for the dilution of the most critical pollutant, the WFN indicates that all other contaminants will be diluted as well. Using several impact categories may give a more comprehensive result while the grey water footprint may pass over important information. Furthermore, the methodology according to the WFN does not consider the eventual cumulative impacts of the polluting substances. For instance, if coffee wastewater is discharged into water bodies, the effluents may cause an increase in the amount of suspended particles in the receiving water bodies. With more nutrients, more matter will be decomposed and levels of oxygen may decrease. And with more suspended particles and higher turbidity, more heat may be absorbed from sunlight, thus heating the water. This may decrease the levels of oxygen even more since oxygen dissolves better in colder water. Moreover, the photosynthetic activity may be reduced due to the suspended particles which scatter the sunlight. With a decrease in the photosynthetic rates, even less oxygen levels will be available and aquatic life may be threatened (Lampert and Sommer, 2007). Consequently, disregarding parameters like the amount of suspended particles could be critical in the overall assessment of the conditions in the water bodies when only looking at the grey water footprint of certain parameters.

The grey water footprint does not reflect prolonged impacts on the water recipients. Pesticides may be persistent pollutants and the theoretical volumes of water may not actually lead to their removal from the water bodies or the environment. If all of the coffee producers in Miraflor pass on the organically-run practices for the next harvest season, the results of the accountings of the water footprint will be substantially lower right away. But, the results will not consider whether the pesticides are persistent in the environment or not.

Another important parameter is the fact that no official data bases are available for the accounting of the water footprint with the WFN standard. The manual of the standard developed by the WFN recommends that, whenever possible, local information should be used. This may have several effects; firstly, regarding the fact that when local data is used on the amount of pesticides and fertilizer applied, these values may be incorrect or even manipulated. It is possible that the farmers may not actually know the rates of application and therefore use estimates when commenting on the numbers. Furthermore, it is not certain that the producers are willing to go public with the information since this can harm their reputation. In this study, we have used information directly from the producers about total application rates of fertilizer. Notwithstanding, as the fertilizers of importance are various, default data available about recommended application rates of the specific fertilizers had to be used. Furthermore, there was no consensus about the application rates of pesticides which is why only default data was used in the accounting. As a consequence, the accounted grey water footprint may be an over- or underestimation depending on the actual pesticide management by the producers in Miraflor. It is also possible that the producers have certain practices in their mixture of fertilizer which have not been covered for in this study.

When accounting for diffuse sources of pollution, there is a lack of available sources for estimations of the leaching-runoff fractions. Using the WFN methodology, calculations could only be made of the substances contributing to a load such as nitrogen, phosphorus and pesticides. Other parameters of importance when looking at the pollution caused by coffee production are the chemical oxygen demand (COD), suspended solids, pH and temperature. These parameters are not covered by the methodology of the WFN in their concept of a pollution contributed by a load. As a consequence, there is a risk that important information about the impacts due to these types of pollution gets lost when leaving out these parameters. Moreover, the effluents actually exceed the threshold values in the Nicaraguan environmental law restricting the discharge of effluent waters from coffee processing plants. According to the law, the pH must be in the range between 6.5 and 9 while the total amount of suspended solids and the chemical oxygen demand cannot exceed 150 mg/l and 200 mg O_2/l respectively (Casa de Gobierno, Nicaragua, 1995).

The model based on leaching-runoff fractions yield results which only will be an estimate of the actual conditions. The model does not tell us anything about the flow path of the chemicals nor the interaction and transformation of the pollutants along their pathways in the runoff or leaching. Nonetheless, the authors of the guidelines of the grey water footprint accounting state that the model is the one that is most commonly used for these calculations, both by business and government, and they expect the model to keep being the most commonly assessed (Franke, Boyacioglu and Hoekstra, 2013). The results may, even if being less detailed, be a first rough estimate of the conditions which predominate in this situation.

Nevertheless and disregarding the above-mentioned issues, the grey water footprint may still be a simple way of showing the gravity of pollution caused by production of certain commodities such as coffee. It all comes back to the final objective of the water footprint study.

5.5 FIELD SAMPLING AND LABORATORY ANALYSIS

The samples show commonly similar values but, as the measured values of phosphorus were considerably higher than the maximum acceptable concentrations, the location where the sampling was carried out may be affected by anthropogenic activities. Consequently, the final values may be uncertain. Notwithstanding, since the grey water footprint component only considers the worst pollutant, the impact of the pesticides would probably still have exceeded the impacts from the active substances in the fertilizers.

5.6 OTHER DELIMITATIONS AND ASSUMPTIONS MADE IN THE STUDY

A choice was made to not account for the water used or consumed by the farmers in Miraflor for drinking or domiciliary activities such as cooking, hygiene or sanitation. In addition, the indirect water used or consumed in the supply chain of the manufacturing of machines or tools used in the coffee production, was not considered. This was made according to the practice of the WFN standards only to include the processes that significantly contribute to the total footprint. These processes generally account for less than 1 % of the overall footprint and hence, they are seen as minor contributors and not significant (Hoekstra et al., 2011).

5.7 SENSITIVITY ANALYSIS

As has been commented on in previous sections in this chapter, there are some uncertainties in the results. In LCA methodology it is common practice to include an analysis of how the uncertainties affect the results which, however, is excluded in the WFN methodology. Notwithstanding, we have chosen to include an analysis of the uncertainties in this study in order to get a better understanding of how the parameters impact on the overall result. The major uncertainties in the study are summarized and briefly commented on below. The result of the sensitivity analysis is shown in table 12.

- **Precipitation data**: The best available data was used as input data in the CROPWAT model. The sensitive analysis (table 12) shows that a change in the precipitation does not affect the total water footprint significantly. However, the green water footprint changes notably with an increase in the precipitation. This is reasonable since a higher availability of water will give a higher evapotranspiration from a reference surface. To get an even better estimate of the potential evapotranspiration, reliable precipitation data from more recent years would be favorable.
- **The average crop water use related to the full life time of the coffee crops**: In order to see how different values of the life time of the crops impact on the results, different life times were used in the sensitivity analysis (table 12). While the overall results do not change significantly, the green water footprint component changes substantially when a short life time is chosen. Consequently, the longer the life time of the crop, the smaller the footprint.
- **Fraction of blue water that evaporates or percolates into the ground**: No specific soil data is available on the soil data in Miraflor and an assumption was made regarding the fractions. Since the blue water footprint component only constitute 0.09 % of the total water footprint, this value is considered as not important for the overall footprint. However, it could still be of importance for the water availability in Miraflor if a larger fraction evaporates and not returns to the same catchment area. In order to get a more accurate value, input data on soil type would be necessary which could be used in a more sophisticated model.
- **Application rates of fertilizers and pesticides**: Values from databases and literature were used to deduce the fractions of the fertilizers and pesticides. In order to see how a change in the input data affects the results, the parameter was increased and decreased with 20 % (table 12). The results change substantially with both an increase and a decrease in the application rates. This is due to the fact that 88.6 % of the overall footprint is linked to the grey water footprint. Consequently, the parameter is one of the more important ones in the study and thus one that to a large extent contributes to the uncertainties of the results. In order to get a more accurate value of the actual application rates and fraction of each substance, a study would

probably have to be carried out over a longer time where participation could be made during the cultivation of the crops.

- **Leaching-runoff fractions:** In order to get a more accurate value, input data on soil type would be necessary which could be used in a more sophisticated model. In order to see how a change in the input data affects the results, the parameter was increased and decreased with 20 % (table 12). Since the leaching-runoff fractions are included in several of the accountings made in this study, the results change significantly with a change in the parameters.
- **Sampling in field:** In order to fully assure that a representative value is used for the natural concentrations, sampling over a longer period of time would have to be carried out. Furthermore, samplings from more locations should be evaluated in order to analyze possible variations in the area.
- **Yield:** Since this study accounts for the water footprint of the production of one season, we have only included the yield of this year. In order to see how the results differ with the yield, we included the parameter in the sensitivity analysis (table 12). A change in the yield substantially changes the overall result since the parameter is included in several of the calculations of the water footprint.

Table 12: *Sensitivity analysis of the uncertainty parameters.*

Parameter	Total water footprint
Average monthly precipitation + 20 %	+ 1.7 % (WF_{green} + 15.2 %)
Average monthly precipitation - 20 %	- 1.0 % (WF_{green} - 8.8 %)
Crop life time 20 years	+ 3.0 % (WF_{green} + 27.2 %)
Crop life time 50 years	+ 1.1 % (WF_{green} + 10.6 %)
Application rates of fertilizers and pesticides + 20 %	+ 17.3 %
Application rates of fertilizers and pesticides - 20 %	- 17.3 %
Leaching-runoff fractions + 20 %	+ 17.3 %
Leaching-runoff fractions - 20 %	- 17.3 %
Yield + 20 %	- 16.7 %
Yield - 20 %	+ 25.0 %

5.8 THE CONSUMPTION VERSUS USE OF FRESHWATER

As previously explained, the WFN methodology addresses the term ‘consumptive freshwater use’. Consequently, the water which is returned or present within the same catchment will not be visible in the accountings of the water footprint. This is debatable since a production potentially could be appropriating a significant volume of water which would not be available to other people or activities within the same catchment. As for the production of coffee in Miraflor, a part of the water abstracted from soil and groundwater resources upstream the plantations for the processing falls under the fraction of used but not consumed water. This fraction stays within the same catchment area and is returned to the same catchment. The question is whether this water could give rise to water issues in the area.

5.9 HOW TO USE THE RESULTS FROM THE STUDY

Nicaragua is considered to be a country with a privilege of hydrological resources (FAO, n.d.) and a low water stress index with a so called *withdrawal-to-availability* (WTA) ratio of 0.03 (GrowingBlue, n.d., based on Pfister et al., 2007). Notwithstanding, water scarcity has been affecting the country recent years and one of the reasons is the contamination of water resources. The municipality of Estelí where the Miraflor region is located is not an exception: the hydrological resources in the area have been contaminated by wastewater effluents from industries as well as the over use of pesticides which have impacted both the surface and groundwater resources (Inifom, n.d.). Moreover, drought has been a problem in the region due to the phenomena of ENSO/El Niño which also was the case of the season of 2015/2016 (FAO, 2015). With the drought in Nicaragua, the coffee production in Miraflor has been affected with a delayed harvest and a lower yield. Other agricultural crops such as corn, plantains, cabbage and potato in the Miraflor region have also been affected (Gutiérrez, E., 2015; Muñoz, 2015). With climate change, problems with drought are expected to increase and one may ask if the production of coffee should be prioritized relative to other products when water is running scarce in the area. This is especially interesting when comparing the water-thirst of the coffee crop with the other crops grown in the area of Miraflor. According to the earlier mentioned study by Mekonnen and Hoekstra (2011) which estimated the water footprints of other crops, corn and plantains have a global average water consumption of 1269 and 1602 m^3/ton respectively while cabbage and potato have an average of 280 and 287 m^3/ton respectively. These values are thus many times smaller in comparison to the estimated water footprint of coffee in the same study which was 15 897 m^3/ton. The sales of coffee constitute the main income for the producers of coffee in Miraflor. Notwithstanding, their coffee grounds could potentially be used to other agricultural practices which still would generate an income.

Regarding the management practices in the production of coffee, improvements are assumed to be possible both with respect to the application of pesticides and fertilizers as well as with respect to the water use. The best solution would obviously be for all the farmers to pass on to an organic management. If this is not fully possible, a better management should at least be considered which should include working on getting a better knowledge of the desirable application rates and the handling of the substances. This would benefit both the workers on the plantations and the people living in the immediate area. Concerning the water consumption in the coffee production in Miraflor and firstly the green water use, better management practices could consist in generating a higher yield per hectare of land which would decrease the green water footprint. According to Hoekstra et al. (2007), the average yield for coffee production in Nicaragua amounts to 4.55 ton/ha while the global average is about 4.53 ton/ha. Thus, the Miraflor average of 2.9 ton/ha is considerably lower. The number could probably increase within a couple of years since the coffee crops have recently started to give yield and the first productive years give a smaller yield (Wintgens, 2004). Furthermore, the study by Hoekstra et al. (2007) used a global average for conventional farming which currently is being debated as to whether this provides higher yields than organic farming (de Ponti, Rijk and van Ittersum, 2012; Jonsson and Landström, 2014).

Improvements could be carried out regarding the treatment of the effluent water from the processing plants. As for the current situation, the only treatment used is the discharge of the water into the basins where it is left to evaporate and percolate into the ground. This does not actually treat the effluents but only move the contaminants and spread them to a wider area, though in smaller concentrations. And since the current management actually violates the law restricting the discharge of effluent waters from coffee processing plants, improvements should be made in order to avoid penalties. Notwithstanding, since no law has been found which regulates the ambient water quality standards in Nicaragua, our guess is that this will not be considered a major problem.

It is the willingness of the producers and the UCA Miraflor that will determine if there will be any wastewater treatment. Among the available methods for a better wastewater treatment is the use of depulper machines without water. This may reduce the polluting effects of the processing since the pulp that is generated from the process breaks down more rapidly. However, in order to use this methodology, new depulper machines would have to be installed which might be expensive (Wintgens, 2004). Another available method is the use of sieves in the washing channels in the processing. With sieves, the organic matter in the effluent water could be held apart from the water and later removed (Wintgens, 2004). The construction costs of larger treatment plants would probably be rather high (following the recommendations by Wintgens, 2004) and there would also be a cost in the labor for managing the installations. As for the current situation in Miraflor, the farmers work in small scale with their activity. Considering installing treatment plants would probably require cooperation between various farmers in order to collect all the effluents to a central treatment site. As a start, other methods such as the ones suggested above could be used in order to reduce pollution caused by the effluents.

The Inifom of Nicaragua (n.d.) estimates that 35.7 % of the inhabitants of the Miraflor region drink water directly from rivers or streams. Knowing this as well as the risks linked to discharging coffee into waterways, together with the fact that the actual management violates the restrictions regarding effluent water standards, improvements should be made in order to secure the well-being of the people living in the area of Miraflor.

6 CONCLUSIONS

The following conclusions can be drawn from the study:

- The final results of the total water footprint show a water footprint of 20 049 m^3 per ton of harvested coffee, where the primary contribution comes from grey water footprint. When considering the total harvest of 2015/2016, the overall water footprint equals a consumption of more than 6 000 000 m^3 of freshwater.
- The results highlight the growing phase as crucial in the consumption of water in which the grey water footprint is the greatest contributor with 88.3 % of the element. This is primarily due to the application of pesticides and when disregarding the use of these substances, nitrogen is the biggest contributor to the grey water footprint in the growing phase.
- Next to the grey water footprint, the green water use is an important component in the cultivation with 11.6 % of the total element.
- There are some uncertainties in the results of the study and in the methodology of the Water Footprint Network (WFN). The major uncertainty parameters in the study are the application rates of fertilizers and pesticides as well as the leaching-runoff fractions of the pollutants. Furthermore, the yield has a large impact on the total results and choosing another year of reference for the study could thus give a different water footprint.
- Using the WFN methodology, the results exclude cumulative effects of pollutants and the results do not reflect the whole pollution situation. Using several impact categories may give a more comprehensive result while the grey water footprint may pass over important information.
- Improvements are assumed to be able to make both with respect to the application of pesticides and fertilizers as well as with respect to the water use. The best solution would be for all the farmers to pass on to an organic management. Better management practices could consist in generating a higher yield per hectare of land which would decrease the green water footprint.
- Regarding the water use in the processing, improvements can be carried out regarding the treatment of the effluent water since the current management violates the law restricting the discharge of effluent waters from coffee processing plants.
- Considering new installations such as a depulper machine and sieves in the washing channels could probably reduce the effluents from the processing. Since the farmers currently are working small-scale and the costs for constructing larger treatment plants could be rather high, installing such methodologies would probably require cooperation between various farmers in order to reduce costs and bring together all the effluents in one place.

7 REFERENCES

7.1 LITTERATURE

Adams, M., Ghaly, A.E., (2006). Maximizing sustainability of the Costa Rican coffee industry. *Journal of cleaner production*, 15: 1716-1729.

AERU, Agriculture & Environment Research Unit, University of Hertfordshire, Hatfield, UK, (2013). *Pesticide properties database (PPDB).* http://sitem.herts.ac.uk/aeru/ppdb [2016-01-15]

AgNova, (n.d.). *Timorex Gold label.* http://www.agnova.com.au/content/custom/products/files/Timorex-label.pdf [2016-02-11]

Allan, J.A., (1998). Virtual Water: A strategic resource. *Groundwater,* 36 (4): 545-546.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization.

Bayart, J.B., Margni, M., Bulle, C., Deschênes, L., Pfister, S., Koehler, A., Vince, F., (2010). Framework for assessment of off-stream freshwater use within LCA. *International Journal of Life Cycle Assessment*, 15 (5): 439-453.

Beyene, A., Kassahun, Y., Addis, T., Assefa, F., Amsalu, A., Legesse, W., Kloos, H., Triest, L., (2012). The impact of traditional coffee processing on river water quality in Ethiopia and the urgency of adopting sound environmental practices. *Environmental Monitory Assessment*, 184 (11): 7053-7063.

Boulay, A-M., Hoekstra, A., Vionnet, S., (2013). Complementarities of Water-Focused Life Cycle Assessment and Water Footprint Assessment. *Environmental Science & Technology,* 47 (21): 11926–11927.

Braham, J.E., Bressani, R., (n.d.). *Coffee pulp. Composition, Technology and Utilization.* https://idl-bnc.idrc.ca/dspace/bitstream/10625/6006/1/IDL-6006.pdf [2016-01-20]

Bydén, S., Larsson, A-M., Olsson, M., (2003). *Mäta vatten – Undersökningar av sött och salt vatten*. Inst. för miljövetenskap och kulturvård, Göteborgs Universitet, Göteborg.

CAPRE, Comité Coordinador Regional de Instituciones de Agua Potable y Saneamiento de Centroamérica, Panamá y República Dominicana., (1993). *Normas de Calidad del Agua para Consumo Humano.* San José, Costa Rica.

Casa de Gobierno, Nicaragua, (1995). Decreto No. 33-95. DISPOSICIONES PARA EL CONTROL CONTAMINACION PROVENIENTES DESCARGAS DE AGUAS RESIDUALES DOMESTICAS, INDUSTRIALES Y AGROPECUARIAS. *La Gaceta Diario Oficial*, No 118, 26 of June 1995, Nicaragua.

Castillo Hernández, E., Calderón Palma, H., Delgado Quezada, V., Flores Meza, Y., Salvatierra Suárez, T., (2006). Situación de los recursos hídricos en Nicaragua. *Boletín Geológico y Minero*, 117 (1): 127-146.

CCME, Canadian Council of Ministers of the Environment, (2013). *Canadian water quality guidelines for the protection of aquatic life*. http://st-ts.ccme.ca. [2016-01-20]

Chanakya, H.N., Dealwis, A.A.P., (2004). Environment issues and management in primary coffee processing. *Process Safety and Environment Protection*, 82 (B4): 291-300.

Chapagain, A.K., Hoekstra, A.Y., (2003). The water needed to have the Dutch drink coffee, Value of Water Research Report Series No. 14, UNESCO-IHE, Delft, The Netherlands. http://temp.waterfootprint.org/Reports/Report14.pdf [2016-01-19]

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R., (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecological Economics*, 60 (1): 186-203.

Chapagain, A.K., Hoekstra, A.Y., (2007). The water footprint of coffee and tea consumption in the Netherlands. *Ecological Economics*, 64 (1): 109-118.

Chapagain, A.K., Hoekstra, A.Y., (2010). The blue, green and grey water footprint of rice from production and consumption perspectives. *Ecological Economics,* 70 (2011): 749–758.

Cleveland, C.C., Houlton, B.Z., Smith, W.K., Marklein, A.R., Reed, S.C., Parton, P., Del Grosso, S.J., Running, S.W., (2013). Patterns of new versus recycled primary production in the terrestrial biosphere. *Proceedings of the National Academy of Sciences,* 110 (31): 12733-12737.

Coltro, L., Mourad, A., Oliveira, P., Baddini, J., Kletecke, R., (2006). Environmental profile of Brazilian green coffee. *The International Journal of Life Cycle Assessment,* 11 (1): 16-21.

Corrales Pérez, D., (2005). *Estudio hidrogeológico del funcionamiento del acuífero de Estelí.* http://www.cira-unan.edu.ni/media/documentos/DCorrales.pdf [2016-02-17]

De Ponti, T. Rijk, B. Van Ittersum, M.K., (2012). The crop yield gap between organic and conventional agriculture. *Agricultural Systems*, 108: 1-9.

EC, European Commission, (1998). *Council Directive 98/83/EC of 3 November 1998: on the quality of water intended for human consumption.* Brussels, Belgium.

EEC, European Economic Community, (1975). *Quality required of surface water intended for the abstraction of drinking water in the Member States, Council Directive 75/440/EEC.* Brussels, Belgium.

EU, European Union, (2013). *Directive 2013/39/EU of the European Parliament and of the Council amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy*. Brussels, Belgium.

FAO, Food and Agriculture Organization of the United Nations, (2008). *Los Recursos Hídricos de Nicaragua.* http://coin.fao.org/coin-static/cms/media/5/12820625348650/fao_nic_recursoshidricos_cepal.pdf [2016-02-16]

FAO, Food and Agriculture Organization of the United Nations, (2010). *CROPWAT 8.0 model*. www.fao.org/nr/water/infores_databases_cropwat.html [2015-09-21]

FAO, Food and Agriculture Organization of the United Nations, (2013). *GeoNetwork.* www.fao.org/geonetwork [2016-01-10]

FAO, Food and Agriculture Organization of the United Nations, (2015). *Central America Drought Update*. http://www.fao.org/3/a-i4926e.pdf [2016-02-18]

FAO, Food and Agriculture Organization of the United Nations, (n.d.). *Los Recursos Hídricos de Nicaragua.* http://coin.fao.org/coin-static/cms/media/5/12820625348650/fao_nic_recursoshidricos_cepal.pdf [2016-02-17]

Franke, N.A., Boyacioglu, H., Hoekstra, A.Y., (2013). *Grey water footprint accounting. Tier 1 Supporting guidelines.* http://production.wfp.fabriquehq.nl/media/downloads/Report65-GreyWaterFootprint-Guidelines.pdf [2016-01-15]

Global Exchange, (n.d.). *Coffee FAQ.* http://www.globalexchange.org/fairtrade/coffee/faq [2016-02-10]

GoogleMaps, (2015). *Reserva Natural Miraflor.* https://www.google.se/maps/place/Reserva+Natural+Miraflor,+Nicaragua/@13.2443913,-86.3061941,12z/data=!3m1!4b1!4m2!3m1!1s0x8f721dde01ddf9a7:0x872166abef8810f5 [2015-10-03]

Green coffee, (n.d.). *What is red coffee cherry-berry superfruit?* www.greencoffee.org [2016-02-11]

GrowingBlue, (n.d.). *The Growing Blue Tool: Nicaragua*. http://growingblue.com/the-growing-blue-tool/ [2016-02-17]

Haddis, A., Devi, R., (2008). Effect of effluent generated from coffee processing plant on the water bodies and human health in its vicinity. *Journal of Hazardous Materials*, 152: 259–262.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., (2011). *The Water Footprint Assessment Manual: Setting the Global Standard.* London, UK: Earthscan.

Humbert, S., Loerincik, Y., Rossi, V., Margni, M., Jollie, O., (2009). Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso). *Journal of Cleaner Production*, 17: 1351 – 1358.

Ineter, Instituto Nicaragüense de Estudios Territoriales, (1988). *Estelí 2955 III, San Rafael del Norte 2955 I, La Sirena 2955 IV.* 1:50000. Managua, Nicaragua.

Inifom, Instituto Nicaragüense de Fomento Municipal, (n.d.). *Estelí.* http://www.inifom.gob.ni/municipios/documentos/esteli/esteli.pdf [2016-02-18]

International Coffee Organization, (2014). *Exporting countries: total production.* http://www.ico.org/prices/po.htm [2015-09-25]

ISO 14040:2006. *Life cycle assessment - Principles and framework*. Environmental management.

ISO 14044:2006. *Life cycle assessment - Requirements and guidelines*. Environmental management.

ISO 14046:2014. *Water footprint - Principles, requirements and guidelines*. Environmental management.

Jefferies, D., Muñoz, I., Hodges, J., King, V.J., Aldaya, M., Ercin, A.E., Milà i Canals, L., Hoekstra, A.Y., (2012). Water Footprint and Life Cycle Assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. *Journal of Cleaner Production*, 33: 155-166.

Jonsson, S., Landström, S., (2014). Ekologiskt jordbruk ger lika stor skörd. *Svenska Dagbladet*, 18 of November 2014. http://www.svd.se/ekologiskt-jordbruk-ger-lika-stor-skord [2016-02-12]

Klöpffer, W., Grahl, B., (2014). *Life Cycle Assessment (LCA): A guide to best practice*. Weinheim, Germany: Wiley-VCH.

Koehler, A., (2008). Water use in LCA: managing the planet's freshwater resources. *The International Journal of Life Cycle Assessment*, 13: 451–455.

Lampert, W., Sommer, U., (2007). *Limnoecology*. Oxford: Oxford University Press.

Landguiden, (2012). *Nicaragua*. http://www.landguiden.se/Lander/Nordamerika/Nicaragua [2015-08-21]

Martinez-Torres, M.E., (2006). *Organic coffee. Sustainable development by Mayan farmers*. Center for International Studies, Ohio University, Athens (Ohio, US).

Mekonnen, M.M., Hoekstra, A.Y., (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, 15: 1577–1600.

NASS, National Agricultural Statistics Service, (2009). *Agricultural Chemical Use Database*.
www.pestmanagement.info/nass [2016-01-20]

Naturskyddsföreningen, (n.d.). *Fördjupning – bekämpning inom ekologisk och oekologisk odling*. http://www.naturskyddsforeningen.se/sites/default/files/dokument-media/rapporter/bekampning-inom-ekologisk-och-oekologisk-odling.pdf [2016-02-05]

Observatory of Economic Complexity, (2014). *Learn more about trade in Nicaragua.* https://atlas.media.mit.edu/en/profile/country/nic/ [2015-09-25]

Overdahl, C.J., Rehm, G.W., Meredith, H.L., (n.d.). *Fertilizer urea*. http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/fertilizer-urea/ [2016-01-20]

Padmapriya, R., Tharian, J.A., Thirunalasundari, T., (2013). Coffee waste management - An overview. *International Journal of Current Science*, 9: 83-91.

Pfister, S., Koehler, A., Hellweg, S., (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environmental Science and Technology*, 43 (11): 4098–4104.

PHCA, Proyecto Hidrometeorológico Centroamericano, (2014). *Cuencas Hidrográficas de Nicaragua bajo la metodología Pfafstetter*. Managua, Nicaragua.

Scharlemann, J.P.W., Hiederer, R., Kapos, V., Ravilious, C., (2011). *Updated global carbon map.* World Conservation Monitoring Centre, United Nations Environment Programme, Nairobi, Kenya.

Schiemenz, K., Kern, J., Paulsen, H-M., Bachmann, S., Eichler-Löbermann, B., (2011). Phosphorus Fertilizing Effects of Biomass Ashes. Insam, H. (red). Knapp, B.A. (red). *Recycling of Biomass Ashes.* Berlin Heidelberg: Springer-Verlag, 17-31.

UCA Miraflor, (2015). *La Unión de Cooperativas "Héroes y Mártires de Miraflor"R.L.* http://ucamiraflor.org/ [2015-10-14]

USDA, United States Department of Agriculture, (2013). *Soils*. www.nrcs.usda.gov/wps/portal/nrcs/site/soils. [2016-01-15]

Water Footprint Network, (n.d. a). *Aims & history*. http://waterfootprint.org/en/about-us/aims-history/ [2015-09-15]

Water Footprint Network, (n.d. b). *What is a water footprint?* http://waterfootprint.org/en/water-footprint/what-is-water-footprint/ [2015-09-15]

Wintgens, J.N., (2004). *Coffee: Growing, processing, sustainable production.* Weinhem, Germany: Wiley-VCH.

The World Bank, (2012). *Climate Change Adaptation Planning in Latin American and Caribbean Cities. Final report: Estelí, Nicaragua.* http://www.worldbank.org/content/dam/Worldbank/document/LAC/esteli.pdf [2016-02-14]

The World Bank, (2015). *Water: Overview.* (http://www.worldbank.org/en/topic/water/overview [2016-01-15]

The World Economic Forum, (2015). *Global Risks 2015.* http://reports.weforum.org/global-risks-2015/ [2015-10-15]

WWF, World Wild Life, (2015). *Threats: Water scarcity.* http://www.worldwildlife.org/threats/water-scarcity [2015-10-13]

Yang, X., Post, W.M., Thornton, P.E., Jain, A., (2013). The distribution of soil phosphorus for global biogeochemical modeling. *Biogeosciences*, 10 (4): 2525–2537.

7.2 PERSONAL CONTACTS

Edwin Gutiérrez. Agronomist at UCA Miraflor. Continuous contact under the period of the field study, September 2015 – December 2015.

Francisco Gutiérrez. Coffee farmer in the community of El Cebollal, Miraflor. 2015-09-23.

José Francisco Muñoz. Coffee farmer in the community of El Tayacán, Miraflor, local biologist/guide in Miraflor and ex-president of the UCA Miraflor. 2015-09-14 & 2015-10-13.

María Maribel González. Coffee farmer in the cooperative of Nuevo Amanecer, Miraflor (UCA Miraflor). 2015-10-01.

Tito Hernández. Coffee farmer in the community of Los Prendedizos, Miraflor. 2015-09-14, 2015-10-13, 2015-10-20 & 2015-12-19.

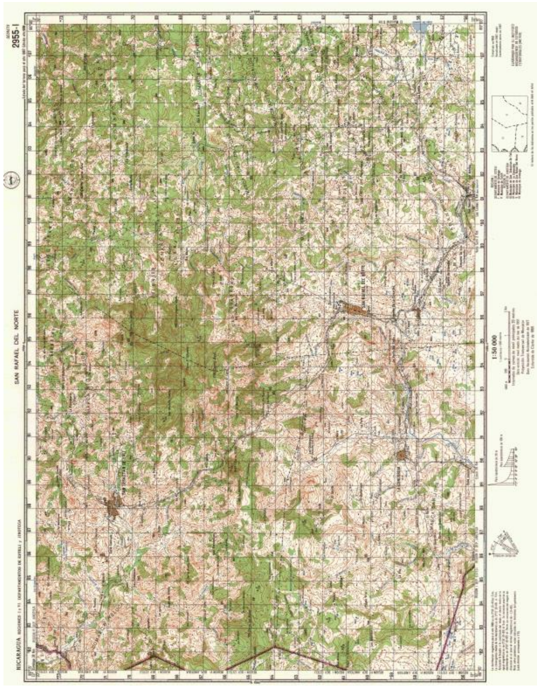
Yoarci Ricardo González, Coffee farmer in the community of El Cebollal, Miraflor and agronomist at UCA Miraflor. Continuous contact under the period of the field study, September 2015 – December 2015.

Ineter, Instituto Nicaragüense de Estudios Territoriales. Climate data 1983-2013 of minimum and maximum temperature, sun hours, humidity and wind speed from the meteorological station in San Isidro. The data also included information about the meteorological station of San Isidro. Information was provided after a visit at the head office in Managua, Nicaragua, 2015-12-10.

APPENDIX

APPENDIX I: Maps of the area of Estelí and Miraflor.
APPENDIX I: Calculations of the green crop water use with the CROPWAT model.
APPENDIX II: Calculations of the grey water footprint.
APPENDIX IV: Calculations of the blue water footprint of processing the coffee beans.

APPENDIX I
Maps of the area of Estelí and Miraflor (Ineter, 1988).

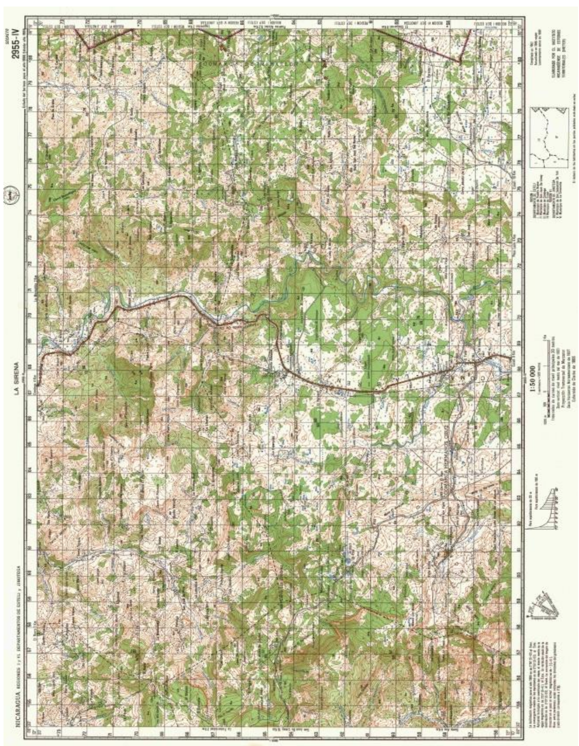


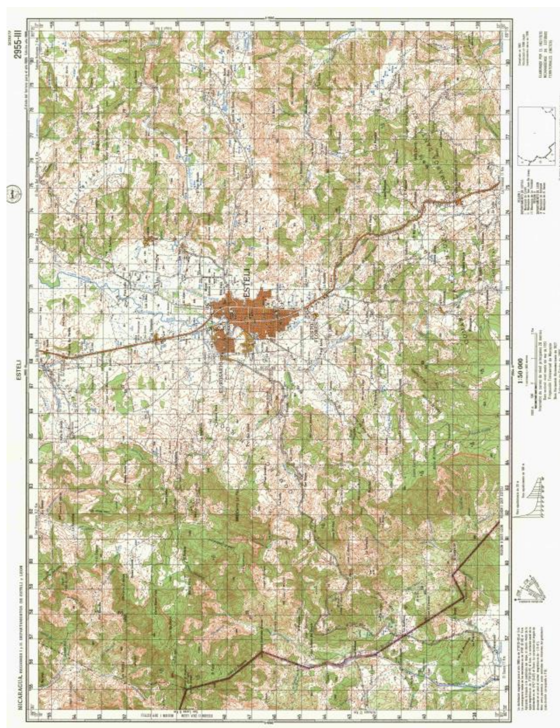
Miniatures of the maps of the Department of Estelí and the area of Miraflor

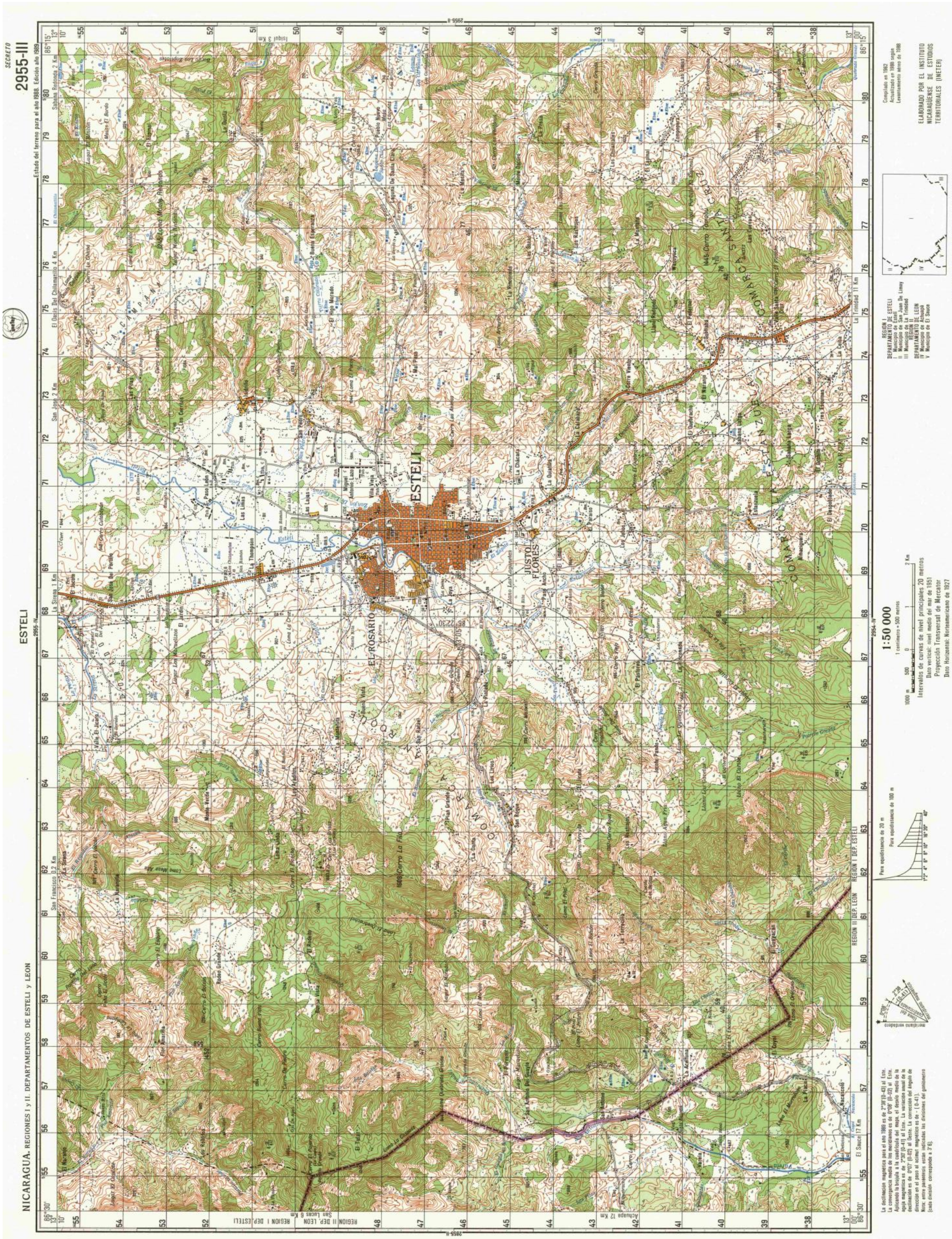
At the bottom, to the right: Department of Estelí – enlargement on page 57.

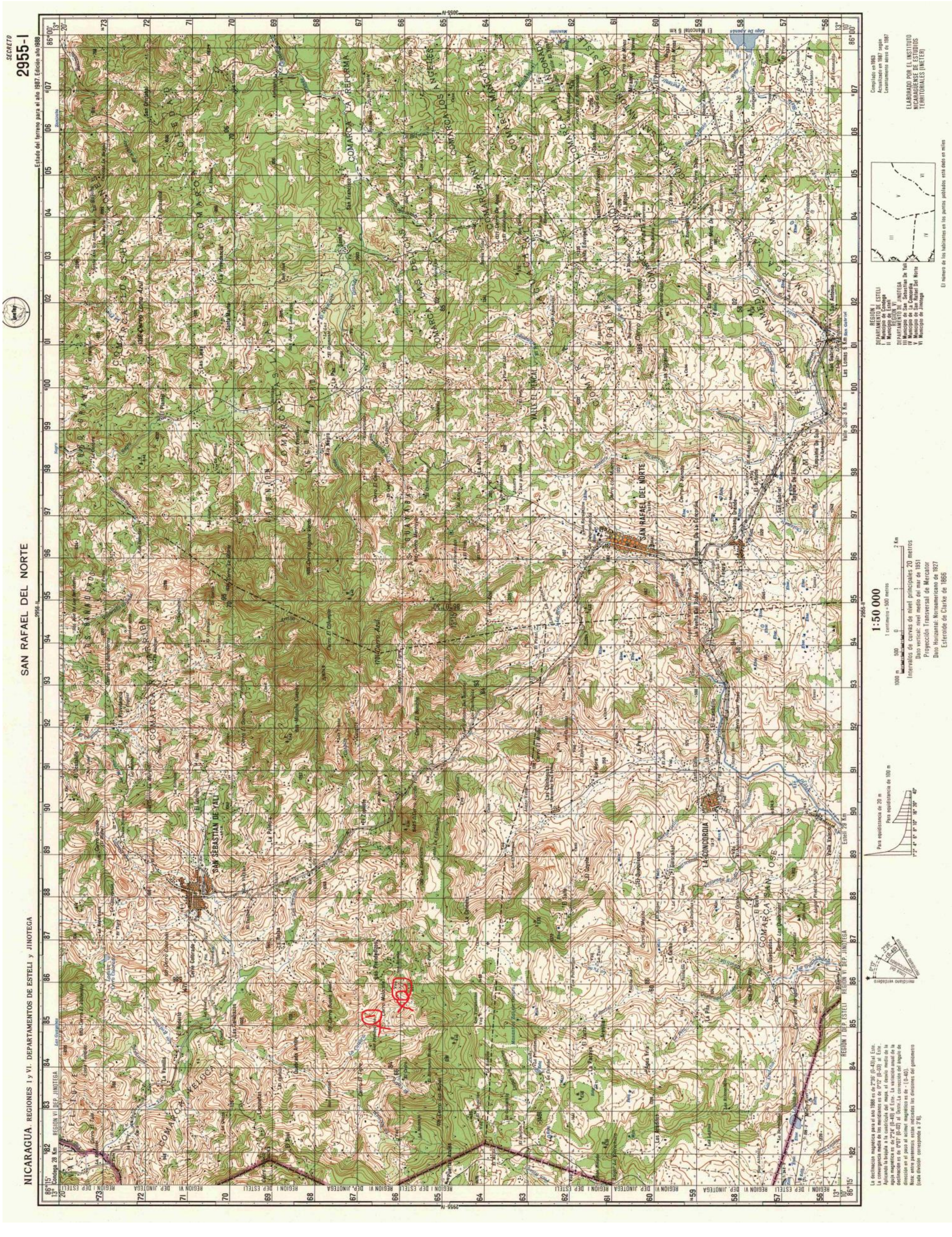
At the top, to the left: Area of San Rafael del Norte – enlargement on page 58 together with an indication of the sampling sites 1 and 2 downstream and upstream the coffee grounds in the area of Los Prendedizos.

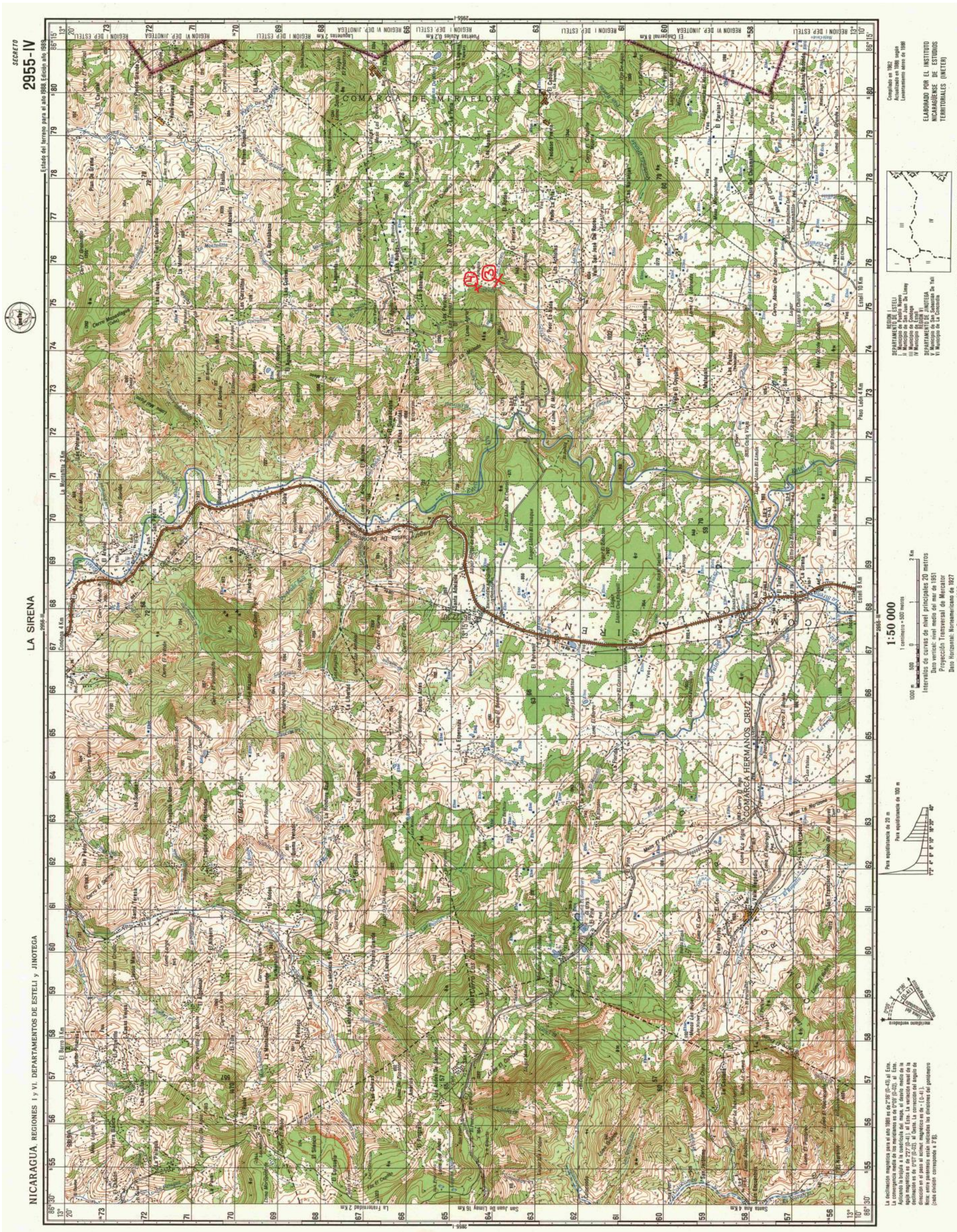
At the bottom, to the left: Area of La Sirena with – enlargement on page 59 together with an indication of the sampling sites 3 and 4 downstream and upstream the coffee grounds in the area of Apagüis/El Terrero.






SECRETO
2955-III
ESTELI
NICARAGUA. REGIONES I y II. DEPARTAMENTOS DE ESTELI y LEON
1:50 000


SECRETO
2955-I
SAN RAFAEL DEL NORTE
NICARAGUA. REGIONES I y VI. DEPARTAMENTOS DE ESTELI y JINOTEGA
SAN RAFAEL DEL NORTE
SAN SEBASTIAN DE YALI
LA CONCORDIA
1:50 000


2955-IV
LA SIRENA
NICARAGUA
COMARCA DE MIRAFLOR
COMARCA HERMANOS CRUZ
1:50 000

APPENDIX II
Calculations of the green crop water use with the CROPWAT model

Radiation and reference evapotranspiration

Daily averages from climate data on minimum and maximum temperature, humidity, wind speed and sun hours were converted into yearly averages. With the input data on climate together with information about the location of the meteorological station, the CROPWAT model returned output data for radiation (Rad) and reference evapotranspiration (ET_o) (figure 12). The CROPWAT model uses the Penman-Monteith method for the determination of the reference evapotranspiration (ET_o) which indicates the evapotranspiration from a hypothetical reference surface not short of water. Thus, the climatic parameters will be the only factors influencing the ET_o (Allen et al., 1998).

Country Nicaragua **Station** San Isidro

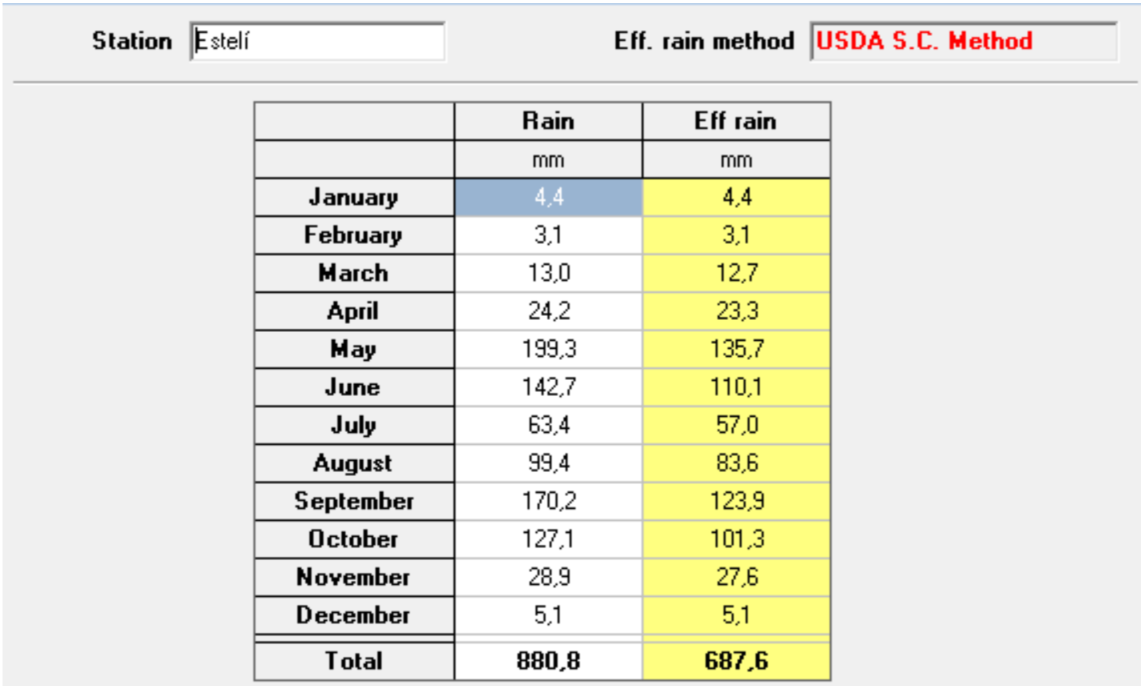
Altitude 480 **m.** **Latitude** 12,54 °S **Longitude** 86,11 °W

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	19,0	30,4	68	304	8,0	22,8	5,67
February	18,8	31,3	67	285	8,6	23,6	5,85
March	19,0	32,4	65	257	9,0	23,3	5,84
April	20,0	33,5	65	223	8,5	20,7	5,33
May	21,1	32,6	73	172	6,4	15,9	3,94
June	21,1	31,1	80	154	5,6	13,9	3,20
July	21,0	31,0	77	187	5,5	14,2	3,46
August	20,8	31,0	78	189	6,4	16,8	3,89
September	20,5	31,2	82	151	6,3	18,4	4,04
October	20,3	30,6	83	148	6,4	19,7	4,23
November	19,8	30,6	77	236	6,9	20,9	4,81
December	19,4	30,5	71	299	7,6	22,0	5,43
Average	**20,1**	**31,4**	**74**	**217**	**7,1**	**19,4**	**4,64**

Figure 12: *The input data on min. and max. temperature, humidity, wind and sun hours together with the returned output data on radiation (Rad) and reference evapotranspiration (ET_o) in the CROPWAT model. Climate data and information about the meteorological station were provided from Ineter (2015).*

Effective rainfall

With input data on the average monthly precipitation, the CROPWAT model calculated the effective rainfall with an empirical formula from the USDA Soil Conservation Service (USDA S.C. Method) which was chosen as default in the CROPWAT model (figure 13). The effective rainfall is the part of the precipitation that does not become runoff or percolates into the ground, i.e. the part which can be effectively used by the crops (Allen et al., 1998).



Station Estelí Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	4,4	4,4
February	3,1	3,1
March	13,0	12,7
April	24,2	23,3
May	199,3	135,7
June	142,7	110,1
July	63,4	57,0
August	99,4	83,6
September	170,2	123,9
October	127,1	101,3
November	28,9	27,6
December	5,1	5,1
Total	880,8	687,6

Figure 13: *The input data on precipitation together with the returned output data on the effective rain in the CROPWAT model. Climate data from The World Bank (2012).*

Coffee crop characteristics

Additional information regarding coffee crop characteristics was necessary in order to run the CROPWAT model. This data included the depletion levels, maximum crop height and root depth as well as the crop factor for coffee (K_c) (table 13). The crop factor depends on effects of crop transpiration and soil evaporation and varies within the season (initial, mid versus end of season) (Allen et al., 1998).

Table 13: *Coffee crop characteristics necessary to run the CROPWAT model (Allen et al., 1998). K_c indicates the crop coefficient which depends on effects of crop transpiration ad soil evaporation and varies within the season.*

	K_c initial	**K_c mid**	**K_c end**	**Max crop height (m)**	**Max root depth (m)**	**Depletion fraction**
Coffee with weeds	1.05	1.1	1.1	2-3	0.9-1.5	0.4

Output values of the crop water use (CWU)

With the input on climate data and crop characteristics the CROPWAT model estimated the crop water requirement (CWR) which could be used to estimate the evapotranspiration and a final value of the crop water use (CWU). The *CWR* indicates the water requirement for crop evapotranspiration (ET_c) from planting to harvest under conditions with ideal growths, i.e. when soil water is maintained by precipitation without limiting plant growth and yield. For coffee, the CWR is calculated over the whole year since coffee is a perennial crop.

By using the effective rainfall, the crop evapotranspiration (ET_c) was calculated over a time step of 10 days over the total growing season (table 14). The ET_c equals the reference evapotranspiration (ET_o) times the crop coefficient (Kc) (equation 15). Since the CROPWAT model calculates the conditions when the crop water requirements are assumed to be fully met, the actual evapotranspiration equals the crop water requirements.

$$ET_c = ET_o \cdot K_c = CWR \qquad (15)$$

Finally, the green water evapotranspiration (ET_{green}) was calculated by using the minimum of the total evapotranspiration and the effective rainfall calculated with a time step of 10 days. This value was later translated into the total crop water use by using a conversion factor 10 (equations 3 and 4) (table 14).

Table 14: *The final output values of the potential green evapotranspiration (ET_{green}) from the CROPWAT model. The values of the ET_{green} were used to calculate the green crop water use (CWU_{green}).*

Month	**Period**	**ET_c (mm/day)**	**ET_c (mm/period)**	**Eff. rain**	**ET_{green}**	**CWU_{green} (m^3/ha)**
Jan	1	5.87	58.7	1.5	1.5	15
Jan	2	5.96	59.6	1.5	1.5	15
Jan	3	6.02	66.2	1.3	1.3	13
Feb	1	6.08	60.8	0.8	0.8	8
Feb	2	6.14	61.4	0.5	0.5	5
Feb	3	6.14	49.1	1.8	1.8	18
Mar	1	6.14	61.4	3.2	3.2	32
Mar	2	6.14	61.4	4.2	4.2	42
Mar	3	5.96	65.5	5.4	5.4	54
Apr	1	5.78	57.8	3.4	3.4	34
Apr	2	5.61	56.1	3	3	30
Apr	3	5.13	51.3	17.1	17.1	171
May	1	4.6	46.5	37.1	37.1	371
May	2	4.17	41.7	51.8	41.7	417
May	3	3.92	43.1	46.8	43.1	431
June	1	3.59	35.9	40.4	35.9	359
June	2	3.3	33	38	33	330
June	3	3.43	34.3	31.6	31.6	316
July	1	3.59	35.9	22.4	22.4	224
July	2	3.68	36.8	15.2	15.2	152
July	3	3.84	42.2	19.4	19.4	194
Aug	1	3.99	39.9	24.5	24.5	245
Aug	2	4.15	41.5	27.3	27.3	273
Aug	3	4.2	46.2	31.9	31.9	319
Sep	1	4.25	42.5	38.8	38.8	388
Sep	2	4.3	43	44.2	43	430
Sep	3	4.37	43.7	40.7	40.7	407
Okt	1	4.55	45.5	37.9	37.9	379
Okt	2	4.63	46.3	36.2	36.2	362
Okt	3	4.84	53.3	27.2	27.2	272
Nov	1	5.06	50.6	15.8	15.8	158
Nov	2	5.27	52.7	6.8	6.8	68
Nov	3	5.5	55	5.1	5.1	51
Dec	1	5.72	57.2	3.5	3.5	35
Dec	2	5.94	59.4	0.7	0.7	7
Dec	3	6.03	66.4	0.9	0.9	9

APPENDIX III
Calculations of the grey water footprint

Estimating the leaching-runoff factor α for the pollutants according to the methodology by Franke, Boyacioglu and Hoekstra (2013)

Table 15: *Minimum and maximum values of α for total nitrogen, total phosphorus and the pesticides as presented in the guidelines by Franke, Boyacioglu and Hoekstra (2013).*

	α_{min}	α_{max}
Total nitrogen	0.01	0.25
Total phosphorus	0.0001	0.05
Pesticides	0.0001	0.1

Table 16: *The influencing factors for the leaching-runoff potential for nitrogen as well as weight and score for each category (Cleveland et al., 2013[1]; Franke, Boyacioglu and Hoekstra, 2013[2]; FAO, 2013[3].*

Factor	Weight (w)	Category	Score (s)
N-deposition[1]	10	0-0.5 g N/m²/yr	0
Texture[2]	15	Silt	0.33
Texture[2]	10	Silt	0.67
Natural drainage[3]	10	Well drained	0.67
Natural drainage[3]	10	Well drained	0.33
Precipitation[3]	15	600-1200 mm/yr	0.33
N-fixation	10	N.A.	0.5
Application rate	10	N.A.	0.5
Plant uptake	5	N.A.	0.5
Management practice[2]	10	Average	0.67

Table 17: *The influencing factors for the leaching-runoff potential for phosphorus as well as weight and score for each category (Franke, Boyacioglu and Hoekstra, 2013[1]; USDA, 2013[2]; Yang et al., 2013[3]).*

Factor	Weight (w)	Category	Score (s)
Texture[1]	15	Silt	0.67
Erosion[2]	20	High	0.67
P-content[3]	15	400-700 g P/m^2	0.67
Rain intensity	10	N.A.	0.5
Application rate	15	N.A.	0.5
Plant uptake	10	N.A.	0.5
Management practice[1]	15	Average	0.67

Table 18*: The influencing factors for the leaching-runoff potential for the pesticides carbendazim and hexaconazole as well as weight and score for each category (AERU, 2015[1]; Franke, Boyacioglu and Hoekstra, 2013[2]; Scharlemann et al., 2011[3]; FAO, 2013[4]*.

Factor	Weight (w)	Category	Score (s)
K_{oc}[1]	20	225/1040	0.67/0
Persistence (half-life in days)[1]	15	40/122	0.67/1
Persistence (half-life in days)[1]	10	40/122	0.67/1
Texture[2]	15	Silt	0.33
Texture[2]	10	Silt	0.67
Organic matter content[3]	10	41 - 80	0.33
Rain intensity	5	N.A.	0.5
Precipitation[4]	5	600-1200 mm/yr	0.33
Management practice[2]	10	Average	0.67

For all of the parameters, $\sum$weight = 100.

Nitrogen

$\sum$ score * weight = 44.15

Using equation 5 and input data from table 15 and 16 gives for nitrogen, α = 0.116.

Phosphorus

$\sum$ score * weight = 61.05

Using equation 5 and input data from table 15 and 17 gives for phosphorus, α = 0.031.

Carbendazim

$\sum$ score * weight = 55.95

Using equation 5 and input data from table 15 and 18 gives for carbendazim α = 0.056.

Hexaconazole

$\sum$ score * weight = 50.8

Using equation 5 and input data from table 15 and 18 gives for hexaconazole α = 0.051.

Estimating the application rates (AR) of fertilizers and pesticides

According to the farmers included in the study, they apply fertilizer in form of urea, wheat straw ash, manure and recycled pulp (coffee skin) (González, 2015; González, M.M., 2015; Gutiérrez, 2015; Hernández, 2015). The total load of fertilizer applied was estimated to be about the same on the two main production sites studied, namely 20 *quintales*/manzana of the coffee grounds (González, 2015; Hernández, 2015). This corresponds to 979 kg/hectare. The substances in the fertilizers that were studied here were nitrogen and phosphorus. The fractions of the substances were estimated according to values in literature (Braham and Bressani, N.d.; Overdahl, Rehm and Meredith, N.d.; Schiemenz et al., 2011). The values are shown in table 19. They were assumed to be applied equally as shown in table 19. With the fractions of nitrogen and phosphorus, the total application rate in kg/year could be estimated, see table 19. For the application rates of pesticides, the farmers did not know the actual load which is applied each year. Consequently, a number was derived from a database (NASS, 2009).

Table 19: *Application rates (AR) of substances in fertilizer and pesticide (González, 2015; Hernández, 2015; Braham and Bressani, n.d.; Overdahl, Rehm and Meredith, n.d.; Schiemenz et al., 2011; NASS, 2009).*

	Total amount of sub-stance [kg/yr]	**Fraction of nitrogen [%]**	**Fraction of phosphorus [%]**	***AR* of nitrogen [kg/yr]**	***AR* of phosphorus [kg/yr]**	***AR* of carbendazim [kg/yr]**	***AR* of hexaconazole [kg/yr]**
Urea	350	47	0	164.5	0	-	-
Ash (straw)	350	0	1	0	3.5	-	-
Manure (cow and chicken)	350	1.1	0.85	3.85	2.98	-	-
Coffee pulp	350	1.9	0.28	6.65	0.98	-	-
Carbendazim	0.36	-	-	-	-	0.36	-
Hexaconazole	0.1325	-	-	-	-	-	0.1325

Estimating the applied load (Appl) of substances from a diffuse source of pollution

It was necessary to calculate the load of substances that is applied each year which origin from diffuse source of pollution, i.e. the honey water which is led from the processing plants to the evaporation/percolation basins.

Knowing the effluent volume and effluent concentration for the honey water from the processing plants together with the time for the process and the amount of beans processed at the time, the variable could be calculated.

An example is given as follows:

(c_{effl} * V_{effl} * process time) / (amount of processed coffee) * total area of plantation

APPENDIX IV

Calculations of the blue water footprint of processing the coffee beans

The volume of blue water for pulping and soaking

Average effluent flow: 0.000266 m^3/s
Average time pulping and soaking: 40 minutes
Amount of coffee processed: 0.0679 ton
Total volume/ton of harvested coffee: 9.39 m^3/ton

The volume of blue water for washing

Average effluent flow: 0.00145 m^3/s
Average time washing: 60 minutes
Amount of coffee processed: 0.0679 ton
Total volume/ton of harvested coffee: 74.22 m^3/ton

Fraction of the volume of blue water for washing which contributes to the effluent flow to the evaporation/percolation basins

Assuming 50 % of the producers use the method: 37.11 m^3/ton

Blue water evaporating in the drying of the coffee cherry

Moisture content before drying: 56.25 % (0.5625 m^3/ton coffee)
Moisture content after drying: 28.4625 % (0.284625 m^3/ton coffee)
Total volume evaporated/ton of harvested coffee: 0.28 m^3/ton