Quantification and analysis of the virtual water “exports” and “imports” related to crop products and the water footprint of national crop production of the Republic of Ecuador

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ABSTRACT

This dissertation investigates the water footprint of national crop production and virtual water ‘flows’ related to crops of the Republic of Ecuador. Calculations were performed to determine Ecuador’s annual water footprint per crop, and annual virtual water ‘exports’ and ‘imports’ per crop. The purpose of this is to determine how Ecuador is handling its valuable water resources. Water used in producing a product is called virtual water. As countries trade agricultural products, virtual water is traded as well, as the water embedded in these products. The results confirm that Ecuador is a net ‘exporter’ of virtual water. Also, there will be evidence showing that on per capita terms, the amount of virtual water ‘exported’ by Ecuador is high, and that these ‘exports’ reflect a growing tendency in the last years. This study has focused on crops because they represent more than 90% of the ‘flow’ of virtual water of Ecuador.
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<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AQUASTAT</td>
<td>Water resources database complied by FAO</td>
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<td>BCE</td>
<td>Ecuadorian Central Bank</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>FAOSTAT</td>
<td>Food and Agriculture Organization of the United Nations Statistics Division</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>HS Code</td>
<td>Harmonized System Code. Harmonized Commodity Description and Coding System of the World Customs Organization</td>
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<tr>
<td>MCM</td>
<td>Millions of cubic metres</td>
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<td>m3/yr.</td>
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<td>m3/yr/cap.</td>
<td>Cubic metres per year per person</td>
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<td>UN</td>
<td>United Nations</td>
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<td>UN COMTRADE</td>
<td>United Nations Commodity Trade Statistics Database</td>
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<td>VW</td>
<td>Virtual Water</td>
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<td>WaterStat</td>
<td>WFN’s global database</td>
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<td>WCO</td>
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1. INTRODUCTION

1.1 Motives, Objectives and Scope

The purpose of this dissertation is to conduct a study on the water footprint of national crop production of the Republic of Ecuador and virtual water "flows" related to these crop products. This is achieved by calculating the approximate annual volume of water embedded in virtual form on the main crops, produced or traded internationally by this country. In daily activities, humans pollute and consume plenty of water, mainly in the production of agricultural products (Hoekstra et al., 2011). The striking figure of 3472 litres per day is the approximate amount of water used to produce agricultural products that a person consumes on average (Mekonnen and Hoekstra, 2011). If we consider only the crop products (excluding animal products), the global average is 2353 litres per day. In addition, international trade causes many agricultural products are transferred to a country other than where it was consumed and polluted the water needed to produce them. This is called the virtual water "flows" or "trade". That is why the water footprint of national production of agricultural commodities of exporting countries such as Ecuador, increases even more through the "export" of water virtually embedded in them.

The purpose of this study is to determine the make-up of Ecuador´s national water footprint for crop production and virtual water ‘flows’ related to crop products. This is achieved via its quantification. For this purpose, the water footprint approach was the analytical tool used. The water footprint is an indicator that helps estimate the volume of water appropriated by humans (Hoekstra et al., 2011). Therefore, the water footprint is just one of the indicators that can help understand in what ways a country is using its water resources and the interdependence with other countries through the virtual water "flows" (Hoekstra et al., 2011).

A study conducted by the Water Footprint Network (WFN) (Mekonnen and Hoekstra, 2011), contains estimates of the total annual average water footprint and virtual water ‘flows’ of Ecuador for the period 1996-2005; however, this study by the WFN does not show a breakdown of water footprint per crop produced within the country. Also, it
does not show a breakdown of virtual water ‘exports’ and ‘imports’ per crop. In other words, the WFN study shows no details and does not mention what are the crop products that compose that total value. In addition it does not contain information of each of the years, but only the average of the ten years in question (1996-2005). This is an issue that has been neglected in the literature and therefore deserves greater attention. Consequently one of the main objectives of this dissertation is to fill the gaps that have been identified and provide new detailed information on the water footprint and virtual water ‘flows’ of Ecuador. This is achieved by calculating and presenting new information on annual water footprint per crop produced, imported and exported by Ecuador. To obtain the water footprint per crop produced, imported and exported by Ecuador, the methodology developed by the Water Footprint Network (WFN, 2014) was used.

This study has focused exclusively on the water footprint of national production and virtual water "flows" of agricultural crops. Total virtual water ‘flow’ is composed of agricultural virtual water ‘flow’ and industrial virtual water ‘flow’. Agricultural virtual water ‘flow’ can be further divided into crop virtual water ‘flow’ and animal products virtual water ‘flow’. In Ecuador, crop products account for 93.97% of total virtual water ‘flow’ (Mekonnen and Hoekstra, 2011). Additionally, crops represent 98.73% of agricultural virtual water ‘flow’ (ibid). Thus, by knowing the data of virtual water ‘flow’ of crop products, the majority of the 'flow' of the total virtual water of Ecuador is known. Was not possible to complement the study with the animal and industrial products because of data and time limitations, characteristics that belong to a dissertation of Master’s Degree.

The calculations were performed over the period 1996 - 2005, since the overall estimates of Mekonnen and Hoekstra (2011) start from this period. For the exports and imports, once I verified that the new calculations I performed were close to the average value given for the period 1996-2005 by Mekonnen and Hoekstra (2011), I proceeded to carry out the calculations for the following years.

1.2 Research Questions
According to the objectives mentioned above, the main questions that are to be answered by this study are:

- What is the make-up of Ecuador’s water footprint of national crop production and virtual water “flows” related to crop products?
- What is the volume of ‘virtual water’ embedded in the main crop products produced, exported and imported by Ecuador?
- To what extent does Ecuador’s water security depend on its own environmental endowments?
- Is Ecuador a net ‘exporter’ of virtual water embedded in crop products?
- To what extent does Ecuador depend on virtual water ‘imports’?

1.3 Study Area

Ecuador has a land area of 283561 square kilometres (Montesino, 2008). It is one of the smallest countries in South America. Despite being a small country, it has three very different climate zones, divided into three vertical stripes arranged from north to south. Located west to east respectively, these areas are: the Pacific Ocean coast (67062 square kilometres), the Andes mountain range (64201 square kilometres) and Amazon rainforest (115613 square kilometres) (Montesino, 2008). Being located on the equator, it has 12 regular hours of light daily throughout the year (ibid). According to the FAO’s AQUASTAT (2014) database, with a long-term average precipitation in depth of 2274 mm/yr., Ecuador is a well endowed with water resources country. These factors contribute to generate a diverse ecosystem, with an abundance of natural resources and a variety of flora and fauna (Montesino, 2008). Besides, these factors enable the production of agricultural products throughout the year.
2. LITERATURE REVIEW

2.1 Food-water (agriculture).

We humans need water not only for drinking or domestic purposes, but primarily we need water to produce the food we consume on a daily basis. As a matter of fact, approximately 92% of the water consumed by humans is intended for the production and consumption of agricultural products (Hoekstra et al., 2011; Shiklomanov, 2000). In overall numbers a human being requires on average about 1385 m3/year per capita of water, including all the water utilized in the production of goods and services for consumption (Mekonnen and Hoekstra, 2011). The average of 1385 m3/year implies that as a worldwide average a person consumes 3794 litres of water daily. Out of those 3794 daily litres, 3491 litres correspond to the consumption of agricultural products (Mekonnen and Hoekstra, 2011). Another 167 litres correspond to the consumption of industrial products (ibid). Only 136 litres correspond to domestic uses (ibid). That means 92%, 4.4% y 3.6%, respectively.

Precisely, the fact that agriculture is a great water consumer and that water is so important for agriculture (Willaarts et al., 2014), has motivated Allan (2013) to divide water consumed by human beings into ‘food-water’ and into ‘non-food-water’. The term ‘food-water’ refers to the necessary water to produce agricultural products required by human beings (Allan, 2013). Within this context, the term food-water includes not only water used for food production. The term food-water also includes water utilized for the production of crops destined to the elaboration of fibres, biofuels and ornamental vegetation (Allan, 2013). On the other hand, the term ‘non-food-water’ refers to the water needed to produce industrial products required by human beings and to the water destined for domestic uses (Allan, 2013).

In spite of what was mentioned on the previous paragraphs, Allan (2011, p.38) points out that the water utilized for food production is, paradoxically, invisible for the general population. This is how the importance of food-water, as a basic component of human nourishment, is invisible to the economy, to politics, and principally to the consumers (Allan, 2013, p. 321). This is due to the fact that, for the consumers that buy goods
and services at local markets, it is hard to observe the great volume of water that is used in the production of those goods and services that they consume (Allan and Wichelns, 2007, p. 1). Precisely, this study pretends to make visible and notorious the volume of water consumed in the production of crop products that Ecuador produces, exports, and imports. This is meant to be done through its quantification.

The fact that the importance of food-water is invisible, meaning that the great volume of water contained (virtually) in the food is not known, is because in the past there was an insignificant amount of people in the world compared to the amount of water there was available (Allan, 2011, p. 18). Nevertheless, in the last century, the world’s population has increased in more than four times (from 1600 million to more than 7000 million) (Gleick, 2000). Along with this, the abstraction of fresh water has increased in more than 7 times (ibid). According to the United Nations (2012), by the year 2050 the world’s population is expected to grow at least 2000 million people more than the current number, leading to an increase in food consumption necessities of 70%. These expectations makes Allan (2002) wonder if there is the right amount of fresh water in the world, needed to satisfy the alimentary needs of future populations, such as the 10000 million people expected in the second half of the twenty first century.

Hence all things mentioned previously, water needed for agricultural production, or “food-water”, is the first element to be taken in account to establish hydrological resources management politics. Precisely, this study will focus on analysing the circumstances surrounding food-water (excluding animal products) contained in Ecuadorian production, exports, and imports.

2.2 Food security and water security

As explained in the previous section, water is fundamental for agricultural production. Meanwhile, agricultural production is fundamental to achieve food security (Willaarts, 2014). Hence there is a direct relationship between ‘water security’ and ‘food security’. According to the FAO (2013, p. 50), food security is “a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”.

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Referring to the term water security, several definitions have been given and there are several ways to understand and conceptualize it. However, Cook and Bakker (2012, p. 97) mentions that “within this diverse literature, four interrelated themes dominate the published research on water security: water availability; human vulnerability to hazards; human needs (development-related, with an emphasis on food security); and sustainability”. There is a highlight on the fact that water security is an essential element to meet human needs and, particularly, to achieve food security for the populations. This will be, precisely, the key aspect of water security that will be relevant for this study. In this sense, Cook and Bakker (2012) argue that there is a tendency that considers that water security is a subdivision of food security. Nevertheless, Flakenmark (2001) alerted in 2001 that it was common to consider food security as something different and independent from the hydrological resources management policies and from water security.

A country can achieve food security by producing locally all the required food (i.e. getting self-sufficiency in food supplies). To achieve food self-sufficiency for the inhabitants of a country, it is essential to have access to the sufficient water resources. However, there are countries where there are not enough hydrological resources, so these cannot be food self-sufficient (Flakenmark, 2001). Then, these countries are obliged to import agricultural products from elsewhere to satisfy the alimentary needs of their populations (ibid). What Allan (1998, p. 545) calls “water-food nexus” can be represented as follows: if there is someone who does not have access to water, it would be more likely for this person to access or acquire a tonne of grains, than to access the 1000 tonnes (or cubic meters) of water required to produce those grains. Here is where the concept of 'virtual water' and the concept of 'virtual water trade' becomes important, as the next section shows. This study is meant to determine to what extent does Ecuador’s water security and food security depend on its own environmental endowments and to what extent does Ecuador depend on virtual water ‘imports’.

Even though the terms food security and food self-sufficiency get confused, in many cases, it has been shown that the actual food imports are what really generate food security (Timmer, 2013). Nevertheless, to achieve food security through food imports,
clearly, the country must have the necessary economic resources to purchase food in the international market. Therefore the water security can be achieved through economic security. Thus Willaarts et al. (2014) state that only partly a country depends on its hydrological resources, since the economical context is what determines its water and food security, ultimately. Whatever the case, this study is interested in finding out if Ecuador is an ‘importer’ or ‘exporter’ of virtual water embedded in crop products.

Regardless of the internal availability of hydrological resources, currently all countries in the world import and export food products and therefore water embedded in them. Consequently, even countries that are well supplied with hydrological resources import large amounts of food supplies. As a matter of fact, currently, every country has some level of dependence on the international trade of agricultural products. For instance, as will be shown in the following sections, although Ecuador is well supplied with hydrological resources, according to the FAO (2012), it has a ‘cereal import dependency ratio’ of 37%. In such manner, for every country in the world, and for Ecuador in particular, it is important to know the level of reliance on foreign hydrological and food resources. This leads to understanding more realistically the situation of water and food security of a nation (Mekonnen and Hoekstra, 2011).

2.3 The Concepts (Virtual Water, Water Footprint, Virtual Water ‘Flow’ and ‘Trade’)

The term “virtual water” is a metaphor that creates a clear link between water and food production. Besides, “virtual water is a term that links water, food, and trade” (Allan, 2003, p. 108). To this extent, this metaphor (the term virtual water) accomplishes two objectives: “describes the water used to produce crop and livestock products that are traded in international markets” and “enhances the understanding of water scarcity, food security, and international trade” (Allan and Wichelns, 2007, p. 1).

According to the Water Footprint Assessment Manual (Hoekstra et al., 2011, p. 193), the term ‘virtual water content’, “refers to the volume of water consumed or polluted for producing a product” (i.e. “is the fresh water ‘embodied’ (virtually) in the product”). Initially, Tony Allan used the term “embedded water”, but in the year 1993, to attain a
better understanding form the public in general, he changed it for the term “virtual water” (Hoekstra and Chapagain, 2008, p. 8). The word “virtual” is used due to the fact that the water used in the agricultural production is not really contained in the final product. (Hoekstra and Chapagain, 2008). A very graphic example of this is that the production of a cup of coffee requires approximately 140 litres of water (Hoekstra and Chapagain, 2008). That would be the volume of water needed to grow a plant of coffee, which will then be used to make the cup of coffee (ibid). It is said that those 140 litres of water used to produce that cup of coffee and that were evaporated in the productive process of the plant are virtually included in that cup of coffee.

The term ‘water footprint’ refers to the same as the term ‘virtual water content’, but it not only refers to the amount of water that is utilized to produce any given product, “but also to the sort of water that was used (green, blue, grey) and to when and where the water was used” (Hoekstra et al., 2011, p. 48). To identify the type of water that makes up the water footprint, the terms green, blue, and grey water footprint have been created. “The blue water footprint refers to the volume of fresh surface and groundwater consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed” (Mekonnen and Hoekstra, 2011b, p. 1578). The green water is rainwater filtrated and stored in the soil (Falkenmark, 2003). On the other hand, grey water footprint is an indicator of pollution in freshwater that can be translated in the amount of water needed to assimilate the contaminants of a productive process (Mekonnen and Hoekstra, 2010). The distinction between the types of water used in crop production is important, since it helps to measure the opportunity cost of consumption and pollution of water. Unfortunately the information on the blue and grey water footprint is not completely reliable in certain developing countries, like Ecuador.

The creation of concept of virtual water also lead to the creation of concepts of virtual water ‘flow’ or ‘trade’. Aldaya et al. (2010, p. 49) defines virtual water ‘trade’ as the volume of water embedded in the products that are being traded. The international food trade means the transfer of water between different countries, in a virtual way, therefore, a virtual water ‘flow’ is produced (Ercin, 2012; Novo et al., 2009). Hoekstra et al. (2011) defines virtual water ‘flow’ as “the volume of virtual water that is being transferred from the one to the another area as a result of product trade”. The virtual
water ‘imports’ help complement the internal deficit that exists in a country, over an imported product and also reduces the pressure there is over the hydrological resources of that country (Hoekstra and Hung, 2002).

Nevertheless, Yang and Zehnder (2008) argue that in spite that water scarcity has been what has motivated a great part of the discussions referring to virtual water, there also exists acknowledgement of water scarcity not being the only reason for virtual water ‘trade’. In fact, they consider that “water scarcity has a relatively limited role in shaping the global virtual water trade flows” (Yang and Zehnder, 2008, p. 17) To that extent, Aldaya *et al.* (2010, pg. 55) argues “that most international food trade occurs for reasons not related to water resources… and that 80% of the ‘virtual water’ trade is mainly due to pure commercial factors.” Precisely this study aims to identify through which crop products Ecuador is 'exporting' and 'importing' virtual water, in order to understand the reasons why the country is 'trading' virtual water.

### 2.4 The Importance of Water to the Environment

The concept of virtual water generates the opportunity to address the management of hydrological resources of importing and exporting countries from a new perspective (Novo *et al*., 2009). However, as Yang and Zehnder (2008) point out, the studies on virtual water have focused almost exclusively on countries that import food supplies. On the contrary, scarce attention has been paid to the impacts that virtual water ‘exports’ could have on hydrological and environmental resources of exporting countries (Yang and Zehnder, 2008). Therefore, there is a shortage of investigation and analysis on the advantages and disadvantages that the international trade of food supplies represents to the virtual water ‘exporting’ countries (Yang and Zehnder, 2008). Through the quantification of virtual water volumes traded by Ecuador, this study precisely pretends to, somehow, provide elements to extend the analysis over how Ecuador is utilizing its hydrological resources.

“In recent years, it has become increasingly evident that local water depletion and pollution are often closely tied to the structure of the global economy” (Ercin *et al*., 2012, p. 7). Around 20% of the decrease and contamination of the hydrological resources of the countries is related to the structure of the international food supply
trade (Ercin et al., 2012)”. It should be pointed out that the greatest ‘crop water productivity’ of food exporting countries, to some extent is due to a higher use of pesticides and fertilizers, which have strong contaminating effects on the environment (Yang and Zehnder, 2008). The interest in increasing production and reducing costs, through the use of these pesticides and fertilizers, has led to a lack of attention to the environmental impacts generated by them (Zehnder et al., 2003). Moreover, even though rainwater (green water) is still the main source of water for agricultural production, the growing demand from the importing countries over the water of the exporting countries, has generated and will keep generating growth of irrigated agriculture (blue water) (Zehnder et al., 2003). This could bring great pressure and a drastic reduction of blue water in the exporting countries (Zehnder et al., 2003). “In the exporting economies there exists only the economic imperative to increase production” (Allan, 2011, p. 159). Trade is absolutely blind to environment concerns (Allan, 2011, p. 159). Presumably, Ecuador, as a virtual water ‘exporting’ country does not escape this reality.

Although 70% of the planet is covered with water, only 2,5% is fresh water and just 0,1% is available for use by nature (Allan, 2011, p. 7). Even though water is a renewable resource, this does not imply that its availability is unlimited and that it can be found at every given moment and everywhere (Hoekstra et al., 2011). In a specific period of time and in a specific territory, the available water is limited only to a determined quantity (Hoekstra et al., 2011). Water is constantly in movement and circulating on earth. Precisely, the water footprint is in charge of estimating how much of this water available on land is being appropriated by humans in a specific period of time, consuming it (evapotranspiration) and contaminating it (Hoekstra et al., 2011). The portion of available water that is not used by humans, serves to maintain natural vegetation and the aquatic ecosystems (Hoekstra et al., 2011). So it is, that available water is not only essential to satisfy human needs, but it is also essential for the conservation of the environment that surrounds us, as well as the necessary environmental services we receive from it (Ercin, 2012). This is why it is absolutely necessary that human beings learn to manage these limited hydrological resources in a way that ensures sustainability.
Furthermore, the negative impacts of agriculture are not only produced on the fresh water sources. Willaarts et al. (2014) point out that the great pace of deforestation that is taking place in Latin America is mainly due to the export oriented agriculture. This especially occurs in the Andean mountain range region and in the Amazon rainforest region, areas that Ecuador belongs to (Willaarts et al., 2014). Deforestation in the Amazon rainforest is a specifically worrisome issue because of the importance of its biodiversity and the ecological role it plays as a regional and global climate regulator. (Willaarts et al., 2014b). Grau and Aide (2008) also note that an important part of the deforestation in the region is produced by the subsistence agriculture, which is, by the way, very important to the household economy in Latin America.

“Current national and global political economies of food production steer farmers towards water managing practices that do not ensure food-water security or towards the increasingly necessary stewardship of ecosystem services” (Allan, 2013, p. 321). “This danger is especially relevant to water ecosystem services” (Allan, 2013, p. 321). The growing economy in Latin America, driven largely by the growth in exports of agricultural commodities and the consequent dependence on natural resources, dangerously compromises the environmental sustainability of the region (Willaarts et al., 2014). In that sense, knowing the water footprint of a country and the virtual water ‘flows’ can be a new way of understanding the impact that hydrological resources management policies of a country can have. Therefore knowing the water footprint of a country and the virtual water ‘flows’ can be used to improve the national policies of hydrological resources management (Ercin, 2012; Mekonnen y Hoekstra, 2011). That is the reason why this study is focused on understanding the make-up of Ecuador’s water footprint and of virtual water flows.

2.5 Reliance of the Ecuadorean Economy on Agriculture

The economic growth in Latin America and Ecuador in the last 15 years has been strongly based in agriculture (Willaarts et al., 2014). According to Willaarts et al. (2014), the high international prices of the agricultural commodities recorded in the years 2007, 2008 and 2012, have been an incentive for Latin America and Ecuador to increase the production and export of food supplies. In Ecuador, the agriculture represents 7% of the Gross Domestic Product (INEC, 2014), however, the agricultural
industry represents 37% of the total exports (BCE, 2014) and provides employment to the 17% of the economical active population (FAO AQUASTAT, 2014). This is how the agricultural production is a very important source of income to Ecuador and a strongly representative portion of the Balance of Trade. On the other hand the oil sector represents 54% of the Ecuadorean exports (BCE, 2014). In such a way, Ecuador strongly depends on the exports of oil and agricultural commodities to support its national economy.

Nevertheless, Willaarts et al. (2014) maintain that the volatility of the international prices of agricultural commodities of the years 2007, 2008 and 2012 is the same volatility that has made many governments come to the conclusion that it is not safe to depend on food supply imports. These governments assume that this dependence is risky, from an economic, political and social point of view (ibid). Therefore, “the notion of food security was thus redefined after the price crises, and food sovereignty is now gaining more prominence to the extent that increasing national food production is becoming an overarching objective in all domains of world and national governance” (Willaarts et al., 2014, p. 6). The concept of food sovereignty has gained strength, causing food self-sufficiency to be sought after. So much so, that in Ecuador, on the year 2009, the so-called Food Security Law was enacted. The Food Security Law redefined the debates on food sovereignty and security.

Moreover, Willaarts et al. (2014b) suggest that the great dependence that Latin America has on green water is not exempt of risk. The potential decrease of agricultural production that represents the unpredictable climatic variability, could indeed imperil food security and the subsistence of many rural households that rely on this activity (Willaarts et al., 2014b). As a matter of fact, natural eventualities, such as El Niño phenomenon, have generated great negative effects on the agricultural situation in Ecuador. As will be seen in the results section, the El Niño phenomenon that took place between November of 1997 and April of 1998, had noticeably strong impacts on the Ecuadorean agricultural production. The eventuality developed subsequent alterations on the virtual water ‘trade’ of Ecuador.
3. RESEARCH METHODOLOGY AND METHODS

3.1 Methodology and Methods

This study is a quantitative data analysis of the water footprint of national crop production and the virtual water “exports” and “imports” related to crop products of Ecuador. This required the individualized calculation of the annual approximate amount of water needed to produce the most representative crop products. For this purpose, the methodology developed by the Water Footprint Network (WFN, 2014) to calculate the annual water footprint of crop products was used. Particularly, the global standard developed by the WFN, denominated ‘water footprint accounting’, was used as a reference to perform the respective calculations (Hoekstra et al., 2011). It is found in the Water Footprint Assessment Manual (Hoekstra et al., 2011). This methodology from the WFN (2014) was chosen because it is a global methodology that standardizes the calculation methods and their assumptions, which therefore makes it possible to have comparable results. Champagain and Tickner (2012) emphasize that, “in an attempt to consolidate a robust and standardized analytical approach, the Water Footprint Network published a Water Footprint Assessment Manual (Hoekstra et al., 2011)”. Besides, this study was conducted using the information available on the WFN online database (called WaterStat). In particular, data given by Mekonnen and Hoekstra (2010 and 2011) was used for the study. The Water Footprint approach was the analytical tool used, as it adjusts to the purposes of this dissertation.

As mentioned in the introduction, Appendix I and II of Mekonnen and Hoekstra (2011) contain an estimate of the total annual value ‘water footprint of national crop production’ and virtual water ‘exports' and 'imports' related to crop products of Ecuador for the period 1996-2005. However, these Appendix I and II only give the total value, and do not contain a detailed breakdown of the crop products that compose the total value, nor the individual values. Therefore, the central objective of this dissertation was to determine which (and in what volumes) are the main crop products that compose this general water footprint of national crop production, as well as the virtual water exports and imports, estimated by Appendix I and II of Mekonnen and Hoekstra (2011) for the period 1996 - 2005. That is why it was necessary to individually calculate
the approximate annual amount of water used to produce the main crop products, exported and imported by Ecuador in those years.

To perform these specific calculations, "the basic approach has been to multiply" the annual amount produced, imported and exported of each crop product (ton/yr.) "by their associated virtual water content (m3/ton)" (Hoekstra and Hung, 2002, p. 7). Estimated values of this associated virtual water content, meaning the amount of cubic meters of green, blue and grey water used in the production of one tonne of each crop product, have been calculated by one of the publications of the WFN (Mekonnen and Hoekstra, 2010). Particularly, the data of the Appendix II of Mekonnen and Hoekstra (2010) was used, since it establishes water footprint per tonne of crop (m3/ton) of all countries of the world (including Ecuador). These values of water consumption per ton, were multiplied by the annual amount of tonnes of each of the main crop products produced, exported and imported (the crop products determined as main are the ones that are more representative due to the annual volumes). The water footprint accounting allows quantifying the water footprint of a geographic area in a specific time (Hoekstra et al., 2011). This study will focus on the amount of water used in the production crop products produced, exported and imported into the territory of Ecuador in annual periods. The specific procedure to be performed to calculate annual water footprint of national crop production and the annual values of virtual water 'exports' and 'imports' related to crop products of Ecuador, is detailed below:

The total values estimated by the Appendix I and II of Mekonnen and Hoekstra (2011) correspond to an average of the ten year period 1996 – 2005. To determine how this total estimates of Appendix I and II is composed, I chose to calculate the annual water footprint of the main crop produced and traded in the years 1996, 1998, 2000, 2002 and 2005. The purpose of this is to obtain an average for the years of period 1996 – 2005. The significant amount of time that takes to elaborate these calculations, would not enable the calculation for all the years between 1996 and 2005. Anyway, the calculation of the five years served to verify if the calculated values match the total value estimated by Mekonnen and Hoekstra (2011). In the Results section it is shown that the values that I calculated indeed are close to that total average estimated by Mekonnen and Hoekstra (2011).
The first step to start the calculations was to obtain information on the annual quantity produced, exported, and imported by Ecuador of each crop product on each year in which the study focused. The information on the quantities produced was obtained from the online database of FAOSTAT (2014) and the information on the quantities exported and imported from the online database of the Ecuadorian Central Bank (BCE, 2014). These data from the BCE (2014) were compared with data from the online database of the UN COMTRADE (2014) and the online database FAOSTAT (2014), in order to comparably verify the validity of data. Then it was very important to become familiar with the details of the quantities produced, imported and exported in each year, to then determine what the most representative crop products for each case are. As will be analysed in detail in the Results section, it was concluded that nine crop products represent 92.51% of the national crop production, ten represent 93.96% of the crop exports and thirteen represent 96.65% of the crop imports. In this sense, by calculating the annual volume of water used to produce those major crops products it is possible to know almost entirely the estimates of the total 'water footprint of national crop production' and the virtual water 'exports' and 'imports' related to crop products.

Once the annual quantity produced, exported and imported of each crop product was obtained, the next step (one of the most complex and critical), was to determine the associated virtual water content per tonne (m3/ton) of each one of them. As mentioned before, the Appendix II of Mekonnen and Hoekstra (2010) establishes the amount of cubic meters of green, blue and grey water required for the production of one tonne of each one of the primary crops (m3/ton) specifically calculated for Ecuador and for all countries in the world. However Mekonnen and Hoekstra (2010) provide several categories and subcategories for each crop product. Therefore, the challenge was to determine precisely to which of these subcategories corresponds each crop product, produced or traded by Ecuador, according to FAOSTAT (2014), the BCE (2014) and UN COMTRADE (2014). For this purpose, the so called 'product code' of the FAOSTAT (2014) and the Harmonized System Code (HS Code), served as a link between data provided by Mekonnen and Hoekstra (2010) and the three databases mentioned. Then these values of water consumption (green, blue and grey) per ton, were multiplied by the number of tonnes annually produced, exported and imported of each of the main crop products. In the case of imports, the water footprint per tonne of crop used was that of the country of origin of the imports.
The final result obtained was the amount of green, blue and grey water used to produce each of the main crop products produced, imported and exported by Ecuador each year. Then, the annual values of each crop product were summed to obtain the total value of the annual water footprint of national crop production and the virtual water 'exports' and 'imports' related to crop products of Ecuador. After obtaining the total annual value of the five years under study, the average of this value was compared with the total values estimated by the Appendix I and Appendix II (Mekonnen and Hoekstra, 2011). With this it was possible to verify that the calculations I performed were close to those of Mekonnen and Hoekstra (2011), as will be discussed in detail in the Results section. Thus, the reliability and validity of the calculations performed were verified.

In the case of exports and imports, once verified that calculations of the virtual water 'exports' and 'imports' related to crop products is close to the average value given for the period 1996-2005 by Mekonnen and Hoekstra (2011), the calculations for the years 2007, 2009, 2011 and 2013 were performed. Values for the years 2007, 2009, 2011 and 2013 were obtained by extrapolation. Even though there was not enough time to do the calculation for all the years of that period, to have the data for the five years allows the observation of how the annual virtual water ‘trade’ of Ecuador has evolved over the whole period. The study for the water footprint of national crop production of the years after 2005 was not performed because of there was not enough time. It should be mentioned that it was necessary to build complex and extensive spreadsheets to obtain the approximate annual volume of water used to produce the main crop products produced, imported and exported by Ecuador.

3.2 Limitations of the Research

This dissertation took as its starting point and basis for the analysis, the water footprint approach of the WFN (2014) and the figures estimated by Mekonnen and Hoekstra (2011). Also used as a basis to perform all calculations, estimates of the water footprint per tonne of crop of Mekonnen and Hoekstra (2010). Therefore, the same limitations and qualifications that have the referenced, exist in this dissertation. The water footprint approach and the figures of Mekonnen and Hoekstra (2010 and 2011) are
only indicators and are also partly founded on assumptions and estimates (Hoekstra et al., 2011). That is why Mekonnen and Hoekstra (2011, p 38) point out that "since all basic sources include uncertainties and possible errors, the water footprint data presented should be taken and interpreted with extreme caution;... but that "despite the plethora of uncertainties, we think that the current study forms a good basis for rough comparisons and to guide further analysis ". Chapagain and Tickner (2012, p. 563) further argue that even though the water footprint analysis is not free of reviews "if used carefully, water footprint tools could contribute to better understanding of the connections between water use, economic development, business practice and social and environmental risks".

Specific examples of such constraints are found, for instance, in the case of the blue water footprint per tonne of crop in Ecuadorian cocoa, coffee and palm oil. Mekonnen and Hoekstra (2010) in the case of these three commodities estimated at zero the blue water footprint per tonne of crop. It is understood that green water is the basis of the production of these crop products, however, it is not appropriate to estimate that blue water is not use at all. Similarly, referring to grey water footprint, there are many limitations, since it "heavily relies on assumptions and estimations" (Galli et al., 2012, p. 106). For example, Mekonnen and Hoekstra (2010) estimated at zero the grey water footprint per tonne of crop in the case of the bananas. This is not accurate. This inaccurate estimate may be due to the fact that “fertilizer application rates per crop per country are not available for most crops” (Mekonnen and Hoekstra, 2010, p. 1597). That is why the distinction of blue water and green water for the production and export of Ecuadorian crop products is not emphasized in the Results section of this dissertation.

Due to these limitations, in this dissertation and specifically in the results section, I have chosen not to emphasize on the distinction between green, blue and grey water footprint. However, the values of the blue and grey water footprint, as detailed in the results section, offer a rough idea of the consumption and pollution of blue and grey water that exists in Ecuador, in relation to crop products.

Note that this is only an exploratory study (Chapagain and Tickner, 2012, p. 575), which has the above limitations and constraints inherent to a master dissertation. For
all these reasons, the results obtained by this dissertation must be considered solely as a general indicator, since specific values require an agronomic and technical study that are outside the scope of the nature of a Master’s dissertation.
4. RESULTS

This chapter will present the results and a discussion about their implications. Particularly, this chapter will present and analyse the most relevant results yielded by the calculations developed as described in the Methodology section. In that sense, first of all, the results referring to the main commodities that compose the annual water footprint of national crop production will be presented and there will be a discussion analysing them. Then, results regarding the virtual water ‘exports’ related to crop products will be presented and there will be an analytic discussion. Finally, results regarding the virtual water ‘imports’ related to crop products will be presented and, as well, a discussion will take place.

The main objective of this study was to generate figures to help identify the most representative crop products that make up the annual water footprint of national crop production and the annual virtual water “trade” of Ecuador. Therefore, as the aim is to present the new figures calculated, it is understood that it is necessary that descriptive information is displayed in this section. The most relevant results and discussion concerning them are presented as follows:

4.1 Water footprint of national crop production

After performing the procedure described in the section of Methodology, it was concluded that there are nine crop products (listed in Table I.), which largely monopolized the production and water footprint of national crop production of Ecuador. According to the FAOSTAT (2014) statistics, during the years 1996-2005, the annual average production of these nine crops reached 16.97 million tonnes and these are broken down as shown in Table I. On the other hand, the annual average of the total crop production of Ecuador reached 18.34 million tonnes. Therefore, those nine crop products represented 92.51% of the total crop production between 1996 and 2005. Consequently, calculating the annual water footprint of these nine crop products, it is possible to know almost the entire annual water footprint of national production of crop products of Ecuador.
To determine the composition of the general estimate given in the Appendix-I of Mekonnen and Hoekstra (2011) for the period 1996-2005, I had to calculate the annual water footprint of these nine main crop products for the years 1996, 1998, 2000, 2002, and 2005. I performed this calculation in order to have an estimated average water footprint of each one of these crop products, on that time period. With these calculations, it was possible to figure out how the water footprint of the total national crop production was composed. The results of the performed calculation are shown in Table II.

<table>
<thead>
<tr>
<th>Crop Product</th>
<th>Annual production (Tonnes)</th>
<th>Green WF (MCM/year)</th>
<th>Blue WF (MCM/year)</th>
<th>Grey WF (MCM/year)</th>
<th>Total WF (MCM/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocoa</td>
<td>82069</td>
<td>2834</td>
<td>0</td>
<td>12</td>
<td>2846</td>
</tr>
<tr>
<td>Coffee</td>
<td>111798</td>
<td>2634</td>
<td>0</td>
<td>15</td>
<td>2649</td>
</tr>
<tr>
<td>Rice</td>
<td>1292635</td>
<td>1775</td>
<td>482</td>
<td>195</td>
<td>2452</td>
</tr>
<tr>
<td>Bananas</td>
<td>5879393</td>
<td>1852</td>
<td>294</td>
<td>0</td>
<td>2146</td>
</tr>
<tr>
<td>Oil palm</td>
<td>1705345</td>
<td>2011</td>
<td>0</td>
<td>73</td>
<td>2083</td>
</tr>
<tr>
<td>Maize</td>
<td>592718</td>
<td>1391</td>
<td>338</td>
<td>230</td>
<td>1958</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>6241821</td>
<td>648</td>
<td>453</td>
<td>22</td>
<td>1133</td>
</tr>
<tr>
<td>Plantains</td>
<td>656093</td>
<td>835</td>
<td>124</td>
<td>0</td>
<td>960</td>
</tr>
<tr>
<td>Potatoes</td>
<td>410424</td>
<td>124</td>
<td>90</td>
<td>61</td>
<td>276</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16972295</td>
<td>11104</td>
<td>1791</td>
<td>607</td>
<td>16503</td>
</tr>
</tbody>
</table>

* Source: based on FAOSTAT (2014)

** A value of zero was assigned to the blue WF of cocoa, coffee and oil palm, and to the grey WF of bananas and plantains, because no information was available for blue and grey WF for these in Mekonnen and Hoekstra (2010).
As shown in Table II., the calculated annual average water footprint of the production of these nine crop products is 16503 millions of cubic meters per year (MCM/yr.) for the time period of 1996 – 2005. On the other hand, Mekonnen and Hoekstra (2011) estimated for the same period of time that the annual average water footprint of national crop production of Ecuador is 17937 MCM/yr (of green, blue, and grey water). Therefore, the amount of 16503 MCM/yr. calculated by this dissertation and exhibited in Table II., represents 92% of the 17937 MCM/yr that Mekonnen and Hoekstra (2011) estimated for the period 1996-2005. It is important to notice that this percentage is similar to the percentage that those nine crop products represented in the volume of the total crop production of Ecuador (mentioned in the first paragraph of this subsection). Thus, the numbers are similar enough to assume that the methodology used by this dissertation is adequate.

The obtained results contain some particularities that will be highlight and analysed:

The total figures mentioned above can be transformed into per capita values with the purpose of making them comparable with other countries and easy to understand. In this case, based on the average population in Ecuador considered for those years by Mekonnen and Hoekstra (2011) (12.3 million inhabitants), the water footprint of national crop production of Ecuador is 3973 litres per day, per person. If we consider only the nine main crop products studied, the water footprint reaches 3656 litres per day, per person. In a manner of comparison, the water footprint of national crop production of the United Kingdom reach 1064 litres per day, per person (Mekonnen and Hoekstra, 2011).

On the other hand, Ecuador´s water footprint of national crops consumed by the inhabitants within the country is 3271 litres per day per person (Mekonnen and Hoekstra, 2011). According to these estimates, the water footprint of national crop production of Ecuador mentioned in the previous paragraph, is higher than the 3271 litres of water footprint of daily consumption of crop products. This means that part of the national crop production is for export, as will be discussed in the following section.

Secondly, it is interesting how the cocoa and the coffee are the commodities with the higher annual water footprint, although the amount produced in tonnes is much less
than other commodities, such as sugarcane and bananas. This is because the amount of water used to produce one tonne of cocoa or coffee is much higher than that used to produce bananas or sugarcane. The water footprint per tonne of crop product that Mekonnen and Hoekstra (2010) estimates for Ecuadorian cocoa and coffee is 34674 m3/ton and 23696 m3/ton, respectively. Meanwhile, the water footprint per tonne of crop product for Ecuadorian banana and sugarcane is 365 m3/ton and 181 m3/ton, respectively.

Figure 1. graphically shows evidence of this eventuality, as it describes the relationship between the percentage that each crop represents in the annual crop production of Ecuador vs. the percentage that each crop represents in the annual water footprint of Ecuador for the period 1996-2005. Sugarcane and bananas, respectively, represented 36.8% and 34.6% of the total crop production volume, but only 6.9% and 13% of the total water footprint of national crop production. On the contrary, cocoa and coffee represented just 0.5% and 0.7% of that production volume, however, they represented 17.2% and 16.1% of that annual water footprint. In conclusion, not only the production volume, but also the water footprint per tonne of product, is an important determinant of annual water footprint of a commodity (Mekonnen and Hoekstra, 2011b).
Figure 1. and Table II. also show that the annual water footprint of national crop production is mostly evenly distributed into six commodities. Thus, cocoa, coffee, rice, bananas, palm oil and corn represented more than 86% of the total water footprint. As an interesting fact, between the first one, which is cocoa (with an annual water footprint of 2846 MCM/yr) and the sixth one, being the corn (with an annual water footprint of 1958 MCM/yr), only existed a difference of 889 MCM/yr.

Additionally, out of these nine main commodities, eight of them are produced mainly on the Pacific Ocean Coast (INEC, 2011). Potatoes are the only product entirely cropped on the Andes mountain range (INEC, 2011) and with a water footprint of 276 MCM/yr these represent only 2% of the total. This reflects that most of the water footprint of national crop production of Ecuador is focused on the coast of the Pacific Ocean. This is because in the Andes mountain range, 41% of arable land is intended for grassland, therefore livestock farming is predominant. That is why the total crops volume produced in the Andes mountain range is less than that produced in the Coast. Meanwhile, in the Ecuadorian Amazon still 53.4% of the land represents uncultivated forests and 32.5% is pastures used for livestock farming as well (INEC, 2011).

Another important feature reflecting the calculated data, is that in 1998 there was a significant decrease in crop production and consequently in the ‘water footprint of national crop production’, as shown in Figure 2. In 1998 the annual water footprint of national agricultural production was 12145 MCM/yr, while the average annual water footprint for the period 1996 - 2005 was 16503 MCM/yr. This was because between November 1997 and April 1998 Ecuador was hit by El Niño atmospheric phenomenon. This phenomenon is an unusual boost in the temperature of the water in the Pacific Ocean, which causes an increase in rainfall and, consequently, severe flooding in Ecuador (Nolivos and Santos, 2009; Willaarts et al., 2014). Paradoxically, the increase in rainfall causes a reduction of the annual water footprint of crop products. This reduction is due to the destruction of crops caused by the high rainfall and flooding and the consequent decrease in crop production. Heavy rain and flooding produced the loss of 53.2% of sugarcane crops, 44.5% of corn crops, 31.2% rice crops, 30% coffee crops, 18.9% cocoa, and 13.6% banana crops (Gasparri et al., 1999). Studies show that there is a high correlation between the magnitude of an El Niño event and its impact on reducing the crop production (Nolivos and Santos, 2009).
Figure 3 (detailed information in Appendix 2.), show in detail the great reduction on the annual water footprint of almost every crop product, in the year 1998. As can be seen, the water footprint of rice, bananas, corn and plantains fell in that year. However, the water footprint that most drastically changed that year is that of cocoa and coffee. The water footprint of the cocoa and the coffee suffered the most severe decline and are the ones that influenced the most on the total water footprint decline. The water footprint of cocoa fell to 37%, from 3253 MCM in the year 1996 to 1214 MCM in 1998. Even though cocoa and coffee were not the most affected crops by the El Niño phenomena, their high water footprint per tonne of crop strongly impacts the total water footprint. It is also noticeable that the water footprint of the oil palm is the only one to experiment an increase in the year 1998.
Finally, the water footprint of national crop production of Ecuador was characterized by the fact that it ended (in 2005) with a similar figure as the one it began (in 1996). Undoubtedly, the sharp decline in 1998 was the most relevant of results. This decline just confirms that Willaarts et al. (2014b) is right when stating that the potential reductions in agricultural production involved in unpredictable climate variability in South America, effectively threaten food security and the livelihood of many rural households that depend on this activity (Willaarts et al., 2014b).

4.2 Virtual water ‘exports’ related to crop products

After performing the procedure described in the methodology section, it was determined that three commodities represent the majority of Ecuador’s virtual water ‘exports’ related to crop products: bananas, cocoa and coffee. Bananas, cocoa, and coffee, on average accounted for 90.93% of the total volume of crop exports from Ecuador. Bananas alone, accounted for 88.51% of those exports related to crop products. However, I included the ten main crop products within the calculations to determine how virtual water ‘exports’ are made up (listed in Table III). This ten crop products represent 93.96% of the total exports related to crop products of Ecuador in the period 1996 – 2005. Consequently, calculating the annual virtual water content of these ten crop products, it is possible to know almost the entire annual virtual water
‘exports’ related to crop products of Ecuador. The results of the performed calculation are shown in Table III.

<table>
<thead>
<tr>
<th>Crop Product</th>
<th>Annual exports (Tons)</th>
<th>Millions of US$ (MCM/year)</th>
<th>Green VW (MCM/year)</th>
<th>Blue VW (MCM/year)</th>
<th>Grey VW (MCM/year)</th>
<th>Total VW (MCM/year)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cacao</td>
<td>72630</td>
<td>104</td>
<td>2720</td>
<td>0</td>
<td>11.2</td>
<td>2732</td>
<td>45.57</td>
</tr>
<tr>
<td>Bananas</td>
<td>4107832</td>
<td>945</td>
<td>1294</td>
<td>207</td>
<td>0.0</td>
<td>1501</td>
<td>25.04</td>
</tr>
<tr>
<td>Coffee</td>
<td>49379</td>
<td>118</td>
<td>1210</td>
<td>0</td>
<td>6.9</td>
<td>1217</td>
<td>20.30</td>
</tr>
<tr>
<td>Fruit, prepare</td>
<td>38251</td>
<td>25</td>
<td>140</td>
<td>13</td>
<td>0.0</td>
<td>153</td>
<td>2.55</td>
</tr>
<tr>
<td>Oil, palm</td>
<td>43910</td>
<td>20</td>
<td>136</td>
<td>0</td>
<td>4.9</td>
<td>141</td>
<td>2.36</td>
</tr>
<tr>
<td>Plantains</td>
<td>81095</td>
<td>13</td>
<td>103</td>
<td>15</td>
<td>0.0</td>
<td>119</td>
<td>1.98</td>
</tr>
<tr>
<td>Rice</td>
<td>16167</td>
<td>6</td>
<td>52</td>
<td>14</td>
<td>5.7</td>
<td>71</td>
<td>1.19</td>
</tr>
<tr>
<td>Flowers</td>
<td>71216</td>
<td>206</td>
<td>6</td>
<td>12</td>
<td>8.8</td>
<td>26</td>
<td>0.44</td>
</tr>
<tr>
<td>Mangoes, mai</td>
<td>20149</td>
<td>8</td>
<td>21</td>
<td>2</td>
<td>2.5</td>
<td>26</td>
<td>0.43</td>
</tr>
<tr>
<td>Pineapples</td>
<td>25050</td>
<td>9</td>
<td>8</td>
<td>0.3</td>
<td>0.8</td>
<td>9</td>
<td>0.15</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4525679</td>
<td>1455</td>
<td>5590</td>
<td>264</td>
<td>41</td>
<td>5995</td>
<td>100.00</td>
</tr>
</tbody>
</table>


** A value of zero was assigned to the blue VW of cocoa, coffee and oil palm, and to the grey VW of bananas and plantains, because no information was available for blue and grey VW for these crops in Mekonnen and Hoekstra (2010)

As show in Table III., the calculated annual average virtual water ‘exports’ of these ten main crop products is 5995 MCM/yr the time period of 1996 – 2005. On the other hand, the Appendix-II of Mekonnen and Hoekstra (2011), states that in that time period the average annual virtual water ‘exports’ related to crop products of Ecuador is 6792.3 MCM/yr. From this average, 6300.3 MCM/yr correspond to green water, 377.7 MCM/yr correspond to blue water and 114.2 MCM/yr correspond to grey water. Therefore, the amount of 5995 MCM/yr calculated by this dissertation and exhibited in Table III. represents 88.26% of the 6792 MCM/yr that Mekonnen and Hoekstra (2011) estimated for the period 1996 - 2005. This percentage is similar to the percentage that those ten crops represented in the volume of total crop exportations of Ecuador (mentioned in the first paragraph of this subsection). Thus, the numbers are similar enough to assume that the methodology used by this dissertation is adequate.

Although bananas alone accounted for 88.51% of those crop exports, cocoa and coffee, respectively, represented 45.57% and 20.30% of the total virtual water ‘exports’, as evidenced in Figure 4. This is, again, due to the high requirement of water to produce one tonne of cocoa or coffee, as mentioned in the previous section.
Once verified that my calculations of the virtual water ‘exports’ related to crop products is close to the average value given for the period 1996-2005 by Mekonnen and Hoekstra (2011), I performed the calculations for the years 2007, 2009, 2011 and 2013 using the same methodology. These calculations involved the years 2007, 2009, 2011, and 2013, particularly. This allowed us to know the tendency of virtual water ‘exports’ related to crop products of Ecuador, as shown in Figure 5. (The Appendix 3. contains the details of the calculations that were used to develop Figure 5.).

Figure 5. shows that there is a clear trend of growth of virtual water ‘exports’ related to crop products. Between 1996 and 2013 there was an increase of 68.83% in the
‘export’ of virtual water, increasing from 7005 MCM/yr in the year 1996 to 11826 MCM/yr in 2013. However, as was expected, in 1998 there was a reduction in virtual water ‘exports’, due to a decrease in the agricultural production, caused by the El Niño phenomenon, discussed in the previous section. By 1998, virtual water ‘exports’ decreased to 4049 MCM/yr, meaning a reduction of 42.20% compared to 1996. As shown in Figure 6, the reduction on virtual water ‘exports’ of cocoa is what mainly influenced the overall reduction of 1998. Virtual water ‘exports’ of cocoa went from 3287 MCM/yr in 1996 to 909 MCM/yr in 1998. After this reduction of virtual water ‘exports’ related to crop products of 1998, it was not until 2005 that the exports reach values close to the ones reached in 1996.

Nevertheless, it is only since 2007 that virtual water ‘exports’ related to crop products started to drastically increase. Thus, between 2007 and 2009 the numbers go from 7449 MCM/yr to 9725 MCM/yr, meaning an extreme increase of 30.55%. Similarly, between 2009 and 2011 the numbers go from 9725 MCM/yr to 11730 MCM/yr, meaning an increase of 20.62%. Therefore, between 2007 and 2011 there was an increase of 57.46%. This is an extremely large increase in ‘exports’ of virtual water. This increase in virtual water exports is believed to be due to the sharp increase in international prices. This way is how the argument of Willaarts et al. (2014), which states that high international prices of agricultural commodities registered in the years 2007, 2008, and 2012, have been an incentive in Latin America and Ecuador for the increase of exports of agricultural commodities, is confirmed to be correct. Between 2011 and 2013, virtual water ‘exports’ related to crop products stabilize again, given that they do not go through any increase during that period.

Figure 6. shows detailed data of the amount of virtual water ‘exports’ related to crop products between the years 1996 and 2013. Though almost all commodities show an increasing trend, it is clearly shown that cocoa has been the product that in the last years has largely contributed to the growth of total virtual water ‘exports’. As cocoa is the main virtual water exporter, the increase of virtual water exports is largely due to this crop. In 1996 and 2007 cocoa reports a similar value of virtual water ‘exports’, 3287 MCM/yr and 3176 MCM/yr respectively. It is only since 2007 that it starts to radically increase, up until reaching 7032 MCM/yr in 2013. It is noticeable how cocoa is a product whose export volume is highly influenced by international prices. Thus,
the international price of cocoa was constantly increased from US$ 1500 per tonne in 2006, to more than US$ 3500 per tonne in 2011 (currently 3100 US$/ton). In the situation of cocoa we can notice that the reasoning given by Willaarts et al. (2014) is correct, saying that high international prices of commodities in the last years are an incentive for the export of crop products.

Calculations show that cocoa, bananas, and coffee dominated the virtual water ‘exports’ related to crop products in the period 1996 – 2005. On average, for the period 1996 – 2005, Figure 7. evidences that the three products sum up 91% of virtual water ‘exports’. Cocoa has the first place, representing 46%, bananas are second with 25%, coffee is third with 20%, and 9% represented by all the rest. Also, Figure 7 shows a further radicalized hegemony of cocoa, representing 59% of the total virtual water ‘exports’ in 2013. It is also worth noticing that, by 2013, the share of bananas and coffee is reduced to 17% and 8%, respectively, giving way to other crop products, such as oil palm, as will be discussed ahead.
Precisely, Figure 8., in which cocoa has been excluded to better visualize the figures of the other crop products, demonstrates the growth that has taken place in virtual water ‘exports’ from oil palm and its derivatives. In 2000, ‘exports’ of virtual water from palm oil were 47 MCM/yr and by 2013 reached 810 MCM/yr. Thus, in 2013 palm oil already represented 7% of total virtual water ‘exports’. As with cocoa, it is thought that palm oil is a product whose export volume is highly influenced by its international prices. The international price of palm oil was constantly increasing from US$ 200 per tonne in the year 2000, to more than US$ 1200 per tonne in 2011, with two very high peaks in 2007 and 2011 (currently 825 US$/ton). With palm oil, once again, it is acknowledged that Willaarts et al. (2014) is correct when saying that the high international prices of agricultural commodities in the last years are an incentive for crop product export in South America.
As for the data of water footprint of national production, the values of the virtual water ‘exports’ can be transformed into per capita values to be comparable and understandable. In this case, based on data provided for the period 1996 - 2005 by Mekonnen and Hoekstra (2011), the virtual water ‘exports’ related to crop products of Ecuador reach 1505 litres per day, per person. If we consider only the ten main crop products analysed in this section, the annual virtual water ‘exports’ reach 1328 litres per person, daily. However, if we consider the figures of the year 2011, with 15.5 million inhabitants, the virtual water ‘exports’ related to the ten main crop products reached 2074 litres per person, daily. Therefore, there was not only an increase in absolute terms, but also in per capita values. That is a lot of water consumed within Ecuador to produce crop products that will be consumed abroad.

4.3 Virtual water ‘imports’ related to crop products

There are four commodities that dominate crop imports and virtual water ‘imports’ related to crop products in Ecuador. This is how for the period 1996 – 2005, wheat, corn, soybean cake and soybean oil, represented on average 79.52% of the total volume of the crops importations (1'227943 tonnes). These four commodities accounted also 72.85% of the virtual water ‘imports’ related to crop products calculated for that period. Nevertheless calculations to determine in what way the ‘imports’ of virtual water are composed, were done including another ten products, with which 96.65% of the total crop imports of Ecuador is constituted.

The Appendix-II of Mekonnen and Hoekstra (2011) states that in the period 1996 - 2005 the average annual virtual water ‘imports’ related to crop products of Ecuador were 2571.59 MCM/yr. Of which, 2150 MCM/yr correspond to green water, 184.4 MCM/yr correspond to blue water, and 237.3 MCM/yr correspond to grey water. Once the calculations as described in the Methodology section were made, the annual average of the virtual water ‘imports’ of the fourteen main crop products imported during the period 1996 – 2005 reached 2309 MCM/yr, as detailed in Table IV. This value represents 89.79% of 2571.59 MCM/yr that Mekonnen and Hoekstra (2011), calculated for the period 1996 - 2005.
As shown in Table VI. and Figure 9, there are indeed four commodities that take up the virtual water ‘imports’, well ahead of the other crop products. Wheat is the strong domineering, accounting as 36.14% of the ‘imports’ of virtual water during those years. Another particular feature worth noting is that 86.32% of virtual water ‘imports’ are green water, 5.54% are blue water and 8.13% are grey water. As stated in the Methodology section, the distinction between green, blue, and grey water is more reliable in the case of importations, than in the case of the Ecuadorian agricultural production water footprint. This is because a large share of crop products imports comes from countries like United States, Canada, and Argentina, whose estimates about the uses of water for production are more refined and reliable. For example, for the period 1996 – 2005, on average 49.83% wheat imports came from United States and 39.42% from Canada.
Once understood how the figures given by Mekonnen and Hoekstra (2011) are composed, about virtual water ‘imports’ related to crop products of Ecuador for the period 1996-2005, the values for the next years were calculated, using the same methodology. Figure 10. and Figure 11. (detailed information in Appendix 4.) show how the virtual water ‘imports’ related to crop products, during the period 1996 – 2011, were distributed and how they evolved. This Figure 10. allows the observation of how wheat, corn, soybean cake, and palm oil are the products that kept hogging the virtual water ‘imports’.

![Crop Products imported by Ecuador](image-url)

**Figure 9.** Annual average virtual water ‘imports’ related to the crop products analysed in this subsection, period 1996 - 2005 (Source: own elaboration, calculations based on raw data from Mekonnen and Hoekstra (2010) and BCE (2014).)
Again, 1998 is the year that shows a special behaviour. As explained above, floods caused by El Niño phenomenon caused a great decrease in agricultural production and the consequent reduction of the national water footprint and virtual water ‘exports’. The reduction of the agricultural production also caused a shortage and scarcity of domestic products in local markets. Ecuador found, precisely, the solution to food shortages suffered in 1998, in the concept of virtual water and virtual water ‘trade’. The virtual water ‘trade’ or ‘flows’ area very powerful and quick remedy for that kind of emergency. According to Allan (2003, p. 111), “water embedded in food commodities
can be mobilized very quickly and flexibly to remedy the ever-changing demands of those enduring water and staple food deficits”.

The virtual water ‘imports’, related to crop products, doubled in 1998, from 1401 MCM/yr (in 1996) to 2704 MCM/yr. As can be seen, the main products (i.e. wheat, corn and, soybean cake) had a sharp increase. However, especially the sugar and rice recorded an unusual volume of virtual water ‘imports’. The destruction of 53.2% of the hectares cultivated with sugarcane and 31.2% of the rice cultivated hectares, as mentioned in section 3.1 (Gasparri et al., 1999), forced imports of these two commodities, that are usually not imported by Ecuador. In fact, 1998 is the only year that presented rice imports. This fact helps us understand the importance of virtual water ‘trade’, even in countries that do not suffer from shortage of water resources.

On the other hand, Figure 10. showed how there is a natural tendency for overall growth of the virtual water ‘imports’ related to crop products. Still, soybean cake is the one product distinguished by its growth, achieving the greatest participation in 2011, even surpassing wheat. This, for the period 1996-2005, wheat represented 34.04% and soybean cake represented 16.14%, and by 2011 wheat accounted for 24.32% and soybean cake 25.12%. Figure 12. shows comparatively, the volume of virtual water ‘imports’ related to crop products belonging to the period 1996 – 2005 and to the year 2011. It is worth mentioning that imported soybean cake is intended for animal feed (e.g. pig, chicken, cattle, sheep), animals which in turn will also be used as human food, mostly. Furthermore, figure 12. evidences the growth of virtual water ‘imports’ of most of the crop products in the last years.
To this extent, it is also important to analyse the dependence of Ecuador on virtual water ‘imports’ related to crop products. For instance, in the case of wheat, Appendix VII of Mekonnen and Hoekstra (2011) estimates that the average water footprint of national consumption of wheat in Ecuador for the period 1996 – 2006, was 84.49 m³/yr/cap, based on an average population of 12.3 million inhabitants (Mekonnen and Hoekstra, 2011). That means a water footprint of wheat consumption of 1045 MCM/yr. On the other hand, Ecuador imported on average 786 MCM/yr embedded in wheat, which transformed to values per capita means 63.55 m³/yr/cap. This implies that Ecuador has a ‘wheat import dependency ratio’ of 75.22%. That is a very high dependence on ‘imports’ of virtual water embedded in wheat.

Similarly, the values of the virtual water ‘imports’ can be transformed into values per capita, so these can be comparable and understandable. For the period 1996 – 2005, with an average population of 12.3 million of inhabitants, the virtual water ‘imports’ related to the main crop products of Ecuador reach 512 litres per person, daily. By the year 2011, with an average population of 15.5 million people, this value came to be 685 litres per person, daily. This means that there not only was an increase on absolute terms, but also in per capita values. In other words, Ecuador has increased its reliance on virtual water ‘imports’ related to crop products. As mentioned before,
part of this increase corresponds to soybean cake, which, once imported, it is used as animal feed, and these animals will end up being used as human food, mostly

Although Ecuador is well endowed with water resources, it relies on the importations of those crop products mentioned in this section. That is the reason why Fader et al. (2013, p. 4) states that “a high proportion of the population of some countries - e.g. Andean countries (Ecuador among them) - relies on crop imports, although not necessarily so, as these imports could be produced on domestic water and land resources”. Many are the reasons mentioned why this may be due, including: “to benefit from comparative advantages, to focus on other economic sectors, or to protect natural ecosystems, or due to lack of capital, labour or know-how” (Fader et al., 2013, p. 4). Anyway, to import water embedded in crop products, in some way, ends up compensating all the virtual water that Ecuador ‘exports’. Garrido et al. (2010, p. 1) claims that importing food products helps preserve the water resources of any country.

4.4 Net virtual water ‘exports’ related to crop products

According to the calculated values, detailed in the previous sections and shown in Figure 13., Ecuador is a net "exporter" country of virtual water. Besides, net virtual water ‘exports’ have gradually increased, both in absolute and in per capita terms, as evidenced in Figures 13. and 14. Thus net "exports" of virtual water increased from 3685 MCM/yr in the period 1996 -. 2005, to 7856 MCM/yr in 2011. On a per capita basis, during those years there was an increase from 816 litres per person, per day to 1389 litres per person, per day. That is an increase of 113.14% overall and 70.22% in per capita terms. As expected in 1998, with 298 litres per person, per day, it was the year in which net "exports" of virtual water were substantially lower.
Figure 13. Total annual virtual water 'flows' related to the crop products analysed by this dissertation. 1996-2011 (Source: own elaboration, calculations based on raw data from Mekonnen and Hoekstra (2010) and BCE (2014)).

Figure 14. Ecuador's daily virtual water 'imports', 'exports' and net 'exports' per person related to the crop products analysed, period 1996-2011 (Source: own elaboration, calculations based on raw data from Mekonnen and Hoekstra (2010) and BCE (2014)).
5. CONCLUSIONS

After having calculated the virtual water content of the main crop products produced and traded by Ecuador, the make-up of the annual water footprint of national crop production and the annual virtual water “trade” of Ecuador were determined. Although the estimates presented in this study have the limitations mentioned in the methodology section, hopefully it can contribute to make more visible and notorious the importance of food-water for food security and for the economy of Ecuador. A key conclusion of this study is that with the production of the crop products that Ecuador exports, precious water and environmental resources are consumed and contaminated. In ‘per capita’ terms Ecuador is virtually ‘exporting’ a great deal of water.

This study was able to confirm that Ecuador is a net ‘exporter’ of virtual water embedded in crop products. This is significant because the crop products account for 93.97% of ‘international trade’ of the virtual water of Ecuador. If we consider only water resource availability, Ecuador is a country that could be self-sufficient in the production of food goods. The results of this study have shown that the water footprint of national crop production of Ecuador is higher than the water footprint of consumption of crop products. Furthermore, this study revealed that both the ‘exports’ as well as the net ‘exports’ of virtual water show a clear upward trend in recent years. It is also clear that the fact that Ecuador is a net ‘exporter’ of virtual water is something that originates in simple economic circumstances, and not as part of a planned and studied decision within the management of national water resources. The international prices of crop products have been determined as an incentive for Ecuador to increase its ‘export’ of virtual water. As mentioned in the literature review section, the exporting countries have economic reasons to encourage farmers to increase production and exports, regardless of the food-water security and environmental considerations (Allan, 2011, Allan 2013).

This growth in exports of food supplies and virtual water embedded in them, certainly brings economic benefits for Ecuador, but also has a strong impact on water resources and environmental assets of the country. It is logical to think that increasing net virtual water ‘exports’ are incrementally reducing and polluting freshwater sources of Ecuador. That is why I believe it is essential that Ecuador develops further studies,
specifically on the volume of blue water and grey water used and polluted in the production of goods that are consumed locally as well as exported. This would help understand the environmental impacts caused by the virtual water 'trade'. As mentioned before, data on the blue and grey water footprint per tonne of crop of the products made in Ecuador, provided by Mekonnen and Hoekstra (2010) are strongly based on assumptions (Galli et al., 2012), due to the lack of information the country has about it. Besides, the large amount of green water that is increasingly being addressed to the production of exported crop products is water that is progressively being taken away from nature and from the environmental services it provides. Importing countries are 'exporting' the water footprint equivalent to the virtual water content of the agricultural commodity (Allan, 2013), consequently, a country that is 'net exporter' of virtual water, such as Ecuador, is 'importing' that water footprint and the environmental damages associated with the production of agricultural commodities exported.

Despite that Ecuador is a net 'exporter' of virtual water, due to circumstances beyond the provision of water resources, the country also has dependency on the import of certain crop products. This confirms that "the concept virtual water is something of a descendant of the concept of comparative advantage "(Allan, 2003, p. 110). Ecuador then has a current dependency on imports, especially of wheat, corn, soybean cake and soybean oil. This means that the food security of Ecuador depends on the import of these four commodities. Ecuador benefits from the low prices of these crop products, usually subsidized by their exporting countries. In any case, it is noteworthy that imports of these crop products help reduce the water footprint of national crop production of Ecuador and somewhat compensate high 'exports' of virtual water recorded. As mentioned in the literature review, every country in the world currently relies, to some extent, on the import of agricultural commodities to achieve food security. For now, food and water security of Ecuador is based on an important water resource endowment, together with the import of certain crop products.

Ecuador records high volumes per capita of water footprint of national production and of virtual water 'exports'; and there is no evidence of political or economic intentions to reduce these levels of consumption and pollution of water. What is clear is Ecuador uses its water resources with an agriculture-oriented focus. One wonders if the
economic decision to increasingly allocate the country's water resources to the production of crop products that are to be exported is sustainable over time and doesn't threaten the water security of future generations.

In the meantime Ecuador has water security, but the circumstances may change over time. This is why I believe it is essential that Ecuador starts planning its strategy for production and export of agricultural products taking into account the consumption and pollution of water needed for production (i.e. food-water).
APPENDIX 1

Copy of the signatures page of Geography Research Ethics Screening Form
Copy of the signatures page of Geography Risk Assessment Form
APPENDIX 2.

Appendix 2. Water footprint per crop of nine main crops produced in Ecuador during the period 1995-2005 (MCM/Year) (Source: own elaboration, calculations based on raw data from Mekonnen and Hoekstra (2010) and FAOSTAT (2014).

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APPENDIX 3.


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APPENDIX 4.


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REFERENCES


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