Water footprint assessment for water stewardship in the agri-food sector

Teresa Lindholm

Master Thesis Series in Environmental Studies and Sustainability Science,
No 2012:011

A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for
Sustainability Studies

Water footprint assessment for water stewardship in the agri-food sector

Teresa Lindholm

A thesis submitted in partial fulfillment of the requirements of Lund University International

Master's Programme in Environmental Studies and Sustainability Science

Submitted May 15, 2012

Supervisors: Sara Brogaard, LUCSUS, Lund University

Aki Finér, Raisio Group

Mira Povelainen, Raisio Group

Abstract

The water footprint assessment framework aims to illustrate the full impact of water consumption in the whole life cycle of a product, from direct water extraction to water pollution. The framework provides a comprehensive indicator for water resources which, if used with care, can provide detailed information about the different impacts of water consumption in order to aid with water stewardship in the agri-food sector. However, the framework suffers from considerable uncertainties caused by discrepancies in the selection of critical limit values, leaching fractions or models and defining the scale of the study.

A case study of oat farming in southwestern Finland and two oat products, oat flakes and an oat drink, is used to illustrate difficulties and opportunities in the application of the framework. The water footprint accounting is done with an applied leaching model and watershed specific nutrient limits for Finland in order to show the importance of the selection of critical parameters. Especially the grey water footprint, a measurement of water pollution and serves as an indicator for water quality, is emphasized as a crucial component in the total embedded water of agri-food products. In this study phosphorus was selected as the critical nutrient in the grey water footprint calculations. Moreover, an alternate impact assessment deviated from the one presented in the water footprint manual is suggested to better illustrate the changes in assimilative capacity of the selected water body.

The water footprint of oat is, in this study, calculated to be highly variable depending on the chosen watershed, the leaching model or fraction, and the natural and maximum phosphorus concentrations defined. The study shows that the water footprint assessment framework can only become valuable as an indicator if the parameters used are carefully selected, while reliable benchmarking can only follow if the parameters are standardized. If the assumptions and methodology used are clearly defined from the onset of the assessment, the framework can serve as a useful internal indicator to show trends in water use and quality. Finally, the study illustrates the importance of considering diffuse pollution when planning water stewardship in the agri-food sector.

Acknowledgements

I would like to thank Aki and Mira for providing so much support and help. I would especially like to thank Aki for not giving up on me even though I at times felt completely out of my element. Further I would like to thank everyone for lovely coffee discussions and providing such a welcoming atmosphere at Raisio.

Thank you to Sara for constantly reminding me of the LUMES perspective and ensuring the academic coherence of my work. Moreover I would like to sincerely thank all of my LUMES classmates and friends for two hectic but forever memorable years. I will always appreciate the many incredible characters I have been able to encounter along the way. Special thanks to my two roommates Lucie and Mert who cooked me dinners when I could not be bothered to. I would also like to thank Emma for constant encouragement and help with my thesis.

Further I would like to thank my biology and Turku friends, who despite leaving them for studies elsewhere always welcome me back with open arms and made my thesis research all the more enjoyable.

Finally I would wholeheartedly like to thank my family for remaining my rock and never questioning my new ventures. Michael, for ensuring I always move forward, and Nina for never doubting that I can make it through.

Table of contents

List of tables

List of equations

List of figures

Abbreviations

BWF	Blue Water Footprint
CCC	Closed Circuit Cultivation CCC®
GWF	Grey Water Footprint
IA	Impact Assessment
LCA	Life Cycle Assessment
N	Nitrogen
P	Phosphorus
WF	Water Footprint
WFA	Water Footprint Assessment
WFD	Water Framework Directive

1. Introduction

Humans are currently consuming 54% of all of the earth's accessible freshwater available in rivers, lakes and underground aquifers (UN water, 2012). With a growing population, continuous overconsumption and maltreatment of our planet's scarce freshwater resources, we are facing freshwater scarcity and quality issues around the world. The additional uncertainty of water availability and accelerated water pollution issues caused by global warming has made the public, private and research sector acknowledge that future water security is a serious issue which needs to be recognized.

Rockström *et al.* (2009) advocates that the earth is subject to a number of planetary boundaries, which if exceeded, permanently alter the ecological equilibrium of our planet. They further propose that we have already exceeded the sustainable threshold for the nitrogen cycle and are close to passing it for phosphorus as well. The unsustainable use of nitrogen and phosphorus pollutes land and water, shifts lake states from clear to turbid, and causes anoxia in our world oceans, bringing about extensive irreversible change in the aquatic ecosystem. Excessive nutrient leaching leads not only to shifts in ecosystem balances, but also causes toxic algae blooms, which can endanger the livelihoods of people by poisoning both fish and livestock drinking unpurified freshwater or, even altogether, render the freshwater unsuitable for human consumption (Carpenter *et al.* 1998). Furthermore, destroying natural ecosystems not only causes immediate threats to peoples' livelihood and health risks, it also deprives them of the less quantifiable intrinsic value of a pristine water body, lowering human wellbeing. Exceeding the natural thresholds not only causes environmental damage and lowers human wellbeing but it also deprives future generations of the right to live on a planet which can provide for them in the same way as it does for us.

Agriculture causes 70-90% of diffuse riverine nitrogen loading and 60-80% of corresponding phosphorus loading, contributing the largest anthropogenic nutrient source (HELCOM, 2011). FAO Aquastat (2012) estimates that the total freshwater withdrawal of actual renewable resources in Finland is 1,458% in 2005, out of which only 0,0455% is used by agriculture. Finland thus has abundant rainfall and freshwater resources, yet still struggles with low water quality, resulting from excessive diffuse leaching of agricultural nutrients. The abundance of water resources can be seen as a valuable asset and a future global competitive advantage for Finnish agriculture and the food processing industry, but to be able to utilize this advantage, water quality issues need to be taken care of. Through examining the current water use and issues, companies can improve their water stewardship practices and better inform their stakeholders, as well as reduce risks, while moving towards a more long-term sustainable water use.

By being able to quantify and visualize water consumption and pollution in a meaningful way, it becomes possible to illustrate the necessity for action and aid in planning for sustainable water use. Practical frameworks are thus called for by decision-makers to aid them in their efforts to improve water stewardship and take steps towards more long-term sustainable freshwater consumption. Stewardship as a concept recognizes that humans have a right to utilize the earth's resources, but condemns excessive use of these resources (Barrett, 1996). This is also reflected in the European Water Partnership's definition; "*the responsible use, management, planning and protection of the natural resource water, ensuring its quality and availability for current and future generations*" (2012). The Water Footprint Assessment (WFA), presented by Arjen Hoekstra in 2003, has increasingly been used by companies to aid them with sustainable water stewardship (Coca-Cola 2010, Rep 2011). Even though the WFA framework is still under development, it can be used as a comprehensive indicator to show the full embedded water volume which is needed to produce a product. The framework aims to quantify not only the direct water use, but also to illustrate the impact water consumption has on water quality and ultimately our water resources. Further, the framework aims to include not only point pollution, but also non-point pollution, as agriculture is one of the main water consuming and polluting activities on our planet.

The first part of this thesis clarifies the aims of this paper and introduces the case study. Section 2 will introduce the origins of the Water Footprint (WF) concept and its use in the industrial and agricultural sector. The third chapter presents the methodology of the WFA. Part 4 consists of a Blue, Green and Grey WF accounting, a product WF analysis of oat flakes and an oat drink, as well as a grey WF and blue WF Impact Assessment. The discussion brings up the larger themes of this thesis and the use of the WFA as a framework in the agri-food sector. Finally, the conclusion sums up the main findings of this paper and suggests some areas for further research.

1.1. Aims

In order for companies to improve their water stewardship, practical frameworks are required for assessing their current water use and impact on water bodies. Simple volumetric water consumption measurements provide only basic information about the long term sustainability of the water use, but do not illustrate the full extent of the impact of the water extraction. Additionally, only relying on volumetric water consumption data from the company facilities completely ignores the water consumption occurring in the supply chain and the additional secondary impacts water consumption has on water quality. The WFA framework divides water use into three different components: green water, the precipitation and evapotranspiration consumed, blue water, the fresh surface or groundwater used, as well as grey water, which represents water pollution. WFA studies have previously focused mainly on blue and green water consumption (Hoekstra & Chapagain 2007, Gerbens-Leenes *et al.* 2009 and many more), with only a few studies examining the third component grey water in more detail (Chapagain *et al.* 2006, Dabrowski *et al*. 2009, Liu *et al*. 2012). Furthermore, the recent study by Dabrowski *et al*. (2009), as well as preliminary results in this study, pinpoints phosphorus as the most critical nutrient in the watersheds studied in this thesis, thus phosphorus is used as the critical nutrient throughout this paper. The objective is thus to explore the WFA framework as a comprehensive indicator for water consumption, particularly in the food sector, which is the major water consumer in the world.

The main aim of this thesis is to critically review the water footprint assessment framework, especially the grey water footprint component, and assess its value for stewardship of water resources in the agri-food sector. Building on this there are three sub-aims to this work:

- To illustrate the use of the WFA through a case study in Finland; particular emphasis is placed on diffuse pollution and water quality, as well as selection of critical parameters in the grey water footprint accounting

- Present the difficulties and opportunities in the grey water footprint impact assessment by using the Finnish case study

- Discuss the usability of the WF framework for unfolding trends and aid with water stewardship in the agri-food sector

In order to discuss the WFA and the Grey Water Footprint (GWF), a case study from oat farming in southwestern Finland and two oat products produced by the agri-food corporation Raisio Group will be examined as examples of the use of the water footprint analysis framework, as well as to illustrate the points of improvement for future use of the WFA framework in water stewardship.

2. The water footprint concept and its origins

Water footprint assessment (WFA) is a relatively new framework which has only been used in the public and private sector since the latter part of 2007 (Hoekstra *et al.*, 2011). The WFA is a retrospective indicator which helps with quantifying and understanding trends in water use (Ness *et al.* 2006). Additionally, WFA is a type of regional flow indicator, which allows for identification of hotspots where efforts in improvements in water stewardship should be focused. The framework aims to give a deeper insight into the water use of a product, community, company or country, by specifying the type of water which is utilized during a life cycle. WFA involves elements which are similar to Life Cycle Assessment (LCA), where water footprint accounting consists of the life-cycle inventory component, and the WF impact assessment and response analysis can be compared to the life cycle assessment stage of a LCA. The blue, green and grey footprints of water contribute to LCA as good indicators of different types of water use (Hoekstra *et al.* 2011). However, the LCA and WFA methodologies are yet developed to be fully compatible; some difficulties remain with the aggregation required for an LCA. Moreover, if the WFA is to be integrated into LCA, the methodology still needs to be better standardized to minimize uncertainty and avoid difficulties such as those presented in this paper.

The WFA framework is based on the concept of virtual water (Allan, 1993), which aims to visualize the water embedded in the production of a product. Virtual water is the total sum of water needed to produce a certain product, including everything from growing or extracting the raw ingredient to processing and finally consuming the good. Embedded water in a product aims to illustrate and internalize not only water use which is directly consumed, but also the water which is consumed in the process required for producing the consumer goods. The concept has helped decision makers in visualizing and internalizing water flows between nations and has been used to help water stressed countries find a political solution to the scarcity issue through international virtual water trade (Wichelns, 2001).

The virtual water concept has increasingly gained attention in the context of national and regional politics because of ongoing discussions about food security and scarce water resources (Wichelns, 2001). Virtual water trade offers a way to alleviate food security threats which are connected to deterioration of water resources by suggesting import of water intensive products from other areas of the world where water resources are more abundant. In a globalized market the concept helps with providing an alternative for optimizing water use and maximizing the value of the limited resource. Moreover, it is not just immediate quantitative lack of water which puts pressure on water resources, also qualitative aspects need to be taken into consideration to ensure the sustainability of the water use. The concept can thus further be used for virtual water quality exports and imports, where the importing country outsources the water quality deterioration associated with the production of the imported good to the exporting country. The WFA thus sees this need for virtual water trade as a basis for developing a framework which can assess which areas need to import or export water in order to achieve a more sustainable water use.

The concept of virtual water is based on the paradigm of weak sustainability as it assumes that natural capital can be replaced, in this case scarce freshwater resources, through importing water from other regions of the world were water is less scarce. This illustrates a world view where manufactured capital, such as processed goods, services or even knowledge, can replace natural capital, and where discounting is acceptable as long as it is managed properly and the broad societal total stock of capital is maintained (Solow, 1993). Weak sustainability acknowledges that the utilization of natural capital in the world can occur inequitably, but assumes that improved resource utilization efficiency will eventually amend such issues. Solow's (1993) view of sustainability claims that if we can only get the price right for natural resources and correct market imperfections and other distortions, humans can create a positive sum of capital for future generations. Weak sustainability is highly compatible with ecological modernization, where growth is assumed to be possible to maintain without endangering the natural environment or human welfare. Virtual water thus implies that responsible trading of embedded water in agricultural or processed food products leads to an increase in the total stock of capital, as we are utilizing the natural capital, freshwater, in a more efficient manner. Equity issues caused by such water trading are assumed to be resolved by compensating the outflow of freshwater with inflow of other forms of capital. WFA is thus a framework to identify the opportunities where freshwater trading efficiency can be improved.

However, virtual water trading does acknowledge that there is a limit to how much water trading can be done in the world, as it assumes a certain critical threshold after which extraction has to stop. Thus virtual water trade does not fully adhere to the mindset of weak sustainability, but recognizes that some extent of irreplaceable natural capital exists. This corresponds with the view of the CRITINC project and their definition of critical natural capital (Ekins, 2003), where certain key natural capital cannot be substituted in a way that would allow it to function to the same extent as it would in its natural form. In accordance with the mindset of planetary boundaries, presented by Rockström *et al.* (2009), the WFA tries to define the critical threshold and measure the stress we are putting on water resources to make sure we are not exceeding the sustainable thresholds for our natural resources.

On the opposite pole of weak sustainability, there is strong sustainability, introduced by Costanza and Daly in 1992, which discredits any discounting of natural capital. If adhering to the principles of strong sustainability, virtual water trading would, in a global perspective, require an extensive restructuring of current water resource flows, so that water would only be exported from water rich countries and imported to water scarce areas. Further, weak sustainability assumes that as long as our resources are used effectively and responsively, there is no limit to growth in consumption (Carter 2007, p. 231), while a strong sustainability approach would require changes in consumption patterns. Even though virtual water can raise consumer awareness about embedded water in products, it does not directly bring about substantial changes in consumption patterns. A shift towards strong sustainability virtual water trading would thus involve a systemic change, which is beyond the scope of what can be done with a framework such as WFA.

Despite the ability of WFA to provide a more detailed insight into the specific components of water use, the framework still has some drawbacks which need to be considered. While some degree of economic impact assessment can be achieved with the WFA, the framework inadequately accounts for social impacts of water use, apart from identifying potential hot spots where the immediate water availability and quality is low. Other impacts of water use, which are not easily quantifiable, are hard to integrate into the WFA because of the nature of the framework. This reveals the discourse of ecological modernization from which the WFA framework has developed. As Hajer states: "*In the most general terms ecological modernization can be defined as the discourse that recognizes the structural character of the environmental problematique but none the less assumes that existing political, economic, and social institutions can internalize the care for the environment. For this purpose ecological modernization, first and foremost, introduces concepts that make issues of environmental degradation calculable. Most notably, ecological modernization frames environmental problems combining monetary units with discursive elements derived from the natural sciences.*" (1995, pg. 25-26). Ecological modernization sees organizing collective action as one of the main obstacles for an environmental friendly society; environmental protection is thus assumed to be an issue of management above other. Furthermore, ecological modernization presumes that there are no fundamental obstacles for a well-organized society to live in harmony with the environment. Finally, ecological modernization assumes that economic growth can be maintained while solving and avoiding environmental issues. Nevertheless, it is not surprising that WF has evolved through the discourse of ecological modernization as it is currently the dominant paradigm in the Western world and international organizations such as the UN, the EU and the OECD (Hajer, 1995).

Oxfam and Kate Raworth (2012) introduce a novel conceptual model of the "sustainability doughnut" which argues that basic human needs should be fused with Rockström's (2011) natural thresholds in order to find "*the safe and just operating space for humanity*" (Raworth, 2012). The UN defined human rights (1948) to safe drinking water, sanitation and food are all linked to the availability of high quality freshwater, and these goals are thus intertwined with the natural thresholds for ecosystems. Raworth (2012) argues that including social justice into the image of the safe space for humanity gives us a better overall picture of the true sustainable operating space for humanity. The argument is that just water stewardship includes fair distribution of water resources as well as ecologically sound use of freshwater, and is a way to ensure that we are staying within both the social and natural thresholds.

Despite the technical difficulties and critique against the concept, virtual water still serves as a useful metaphor in water stewardship. The majority of the freshwater is today consumed in agricultural products, but water is also used in many other industrial processes. Direct water use such as irrigation is reasonably simple to estimate, but the predicament lies in calculating more complex uses of water, such as soil water, and to quantify the amounts in meaningful ways. The WFA provides only one perspective and model for conceptualizing the water utilization, but nevertheless it allows for a more extended insight into the true impact of water use than simple water volume and quality measurements are able to present. Further, it allows us to visualize global flows of water through trading of commodities, showing us the impact our consumption has on water resources, and pointing out the weaknesses and opportunities in the current system.

2.1. Water footprint in the industrial sphere

One of the aims of the WFA framework is to give its users a more comprehensive overview of the current water consumption, not only the operational water use, but also the water use in the supply chain. The benchmarking report by Barton (2010) found a substantial lack of knowledge about water use and risk reporting especially for the supply chain side of the private sector. Considering that the majority of the water consumption takes place in the supply chain, this is a definite cause for more attention. Despite mentioning water in their annual reports, few companies provide any kind of specification or quantification of the risk involved with the current water consumption, making it hard for investor’s to gain any insights. Moreover, setting and disclosing specified reduction targets were rare amongst the studied companies. Finally, poor water management and reporting cause potential reputational risks, but despite this, little stakeholder interaction is conducted to engage other parties in the private water stewardship (Barton, 2010).

Business risks related to water can be either direct, through immediate lack of clean water for vital processes in industry or energy production, or indirect, such as reputational, regulatory or litigation risks (Barton, 2010). Besides potential financial loss caused by industrial complexes being forced to increasingly clean incoming and outgoing water or even altogether running out of usable water, the growing attention to water related issues has emphasized the UN human right to clean water (UN, 1948). Increasing discussion emphasizing the right to clean water in turn has raises the likelihood of reputational scandals when bad water stewardship is revealed, enhanced the societal pressure on more stringent regulation and increased the law suits filed on basis of wasteful or irresponsible use of water resources (Barton, 2010).

In the private industrial sector, a framework such as the WF can be used for identifying potential risks and vulnerabilities as it identifies problem areas where water stewardship can be improved. Having an overview of the total water consumption is also essential from a corporate social responsibility point of view. However, for the WF analysis to be usable in a wider industrial context, the methodology needs to be reliable, and the results have to be comparable both within the same sectors as well as between different sectors. This study aims to examine whether the WFA fulfills these criteria in order for it to become a valuable framework for water stewardship in the agri-food sector.

2.2. Water footprint in the agri-food sector

Previous studies have shown that the majority of the freshwater we consume is used in agriculture as up to 70% is used for irrigation (UNEP, 2012). Agriculture and food production will always utilize water, thus achieving a WF of zero will never be possible, which is a major difference from other products which do not use renewable raw material and thus only require water in the processing. The WF framework allows for an analysis and comparison of different agricultural products, produced in different parts of the world using varying farming practices, and thus enables a selection of the most appropriate alternative from a water stewardship perspective. The WF IA gives additional valuable information which helps identify problem areas where immediate action needs to be taken, or potential risk areas where the agriculture is done on an unsustainable basis. The WFA also shows where water resources are abundant and sustainably managed, allowing food industries to select the raw ingredients from areas where water use is handled in a responsible manner. Within the water intensive agricultural sector, the WFA can thus aid in making better decisions and inform the food industry about the water use in the supply chain as well as the production facilities.

3. Methodology

The WFA consists of four stages (Figure 1). The WFA consists of a green water footprint, the rainwater evapotranspiration plus the precipitation incorporated into the crops, a Blue Water Footprint (BWF), the fresh surface or groundwater, as well as a Grey Water Footprint (GWF), which is the amount of water that is required to dilute a critical pollutant.

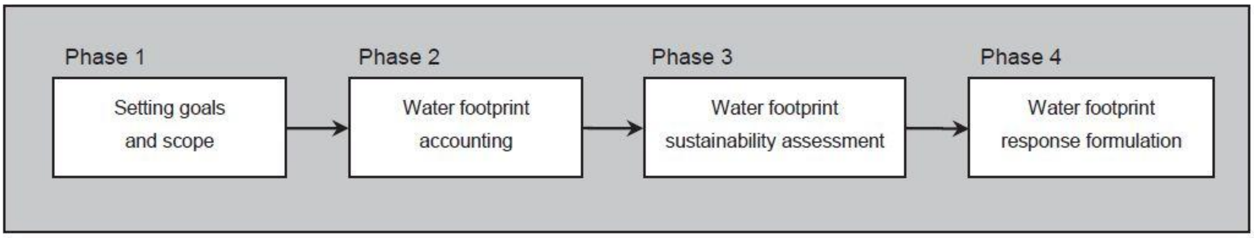

Figure 1: The different phases of WFA (from Hoekstra et al. 2011)

3.1. Blue water footprint

The BWF represents all the water abstraction which has an impact on the water body it is extracted from (Hoekstra *et al.* 2011). If freshwater is not restored to its original water body in the same quantity and quality as before the extraction, then the water resource is being depleted and disturbed by the human consumption. Any water extraction which disturbs the natural ecosystem by temporarily disrupting its natural balance, even if the water is returned at a later point, should still be included in the BWF accounting. BWF is thus a measurement of direct water consumption of surface or groundwater resources. The BWF is in this study based on the direct water consumption which has been measured by the production facilities as well as calculated for the BWF of energy used in the facilities, both for producing heat and for electricity.

3.2. Green water footprint

The green water footprint is the precipitation consumed by the crops during their growth period. To estimate the green water footprint the CropWat tool developed by FAO (1998) has been used. As the CropWat program is endorsed by the FAO, it has developed into a tool which is regularly used for estimates of evapotranspiration, and it is thus suggested as a valid option for green WF calculations in the WF manual (Hoekstra *et al.* 2011). The crop water requirements are in CropWat calculated for ideal growth conditions, meaning when the crop, in this case oat, has access to adequate soil water for optimal growth and yield (Hoekstra *et al.* 2011, pp. 131). CropWat results are calculated with the crop coefficient (K_c) values set as 0,25 (initial), 1,15 (mid-season) and 0,25 (late season) according to Allen *et al*. 1998. The growth period of oats is set at 92 days (Allen *et al*. 1998), starting the 10th of May 2011 (Laurinen, personal communication, 2012). Climate and rainfall data for 2011 was acquired from the Finnish Meteorological Institute. The potential evapotranspiration (ET_0) is as a default in CropWat calculated with the Penman-Monteith method. The effective precipitation (P_{eff}) is estimated with the method of the United States Department of Agriculture, Soil Conservation Service (USDA SCS method). CropWat calculation (Allen *et al*. 1998) are based on Equation 1.

$$\text{Crop Water Requirements (CWR)} = K_c \times ET_0 \qquad \text{(Eq. 1)}$$

K_c = crop coefficient (constant)
ET_0 = potential evapotranspiration (mm)

The green WF is then calculated based on the results from the CropWat analysis as the minimum between total crop evapotranspiration and effective rainfall and converted to a green component (m^3/ha) by applying a factor of 10 which converts water depth in millimeters to a water volume per hectare (Hoekstra *et al*. 2011). Finally the green component is divided by the crop yield reported by the farmer to produce the final volumetric green WF.

3.3. Grey water footprint

Calculations for water pollution in the WFA are derived from the concept of a 'critical load', which determines the assimilation capacity of a water body by multiplying the total water flow with the difference between the maximum and natural concentration of a substance (Hoekstra *et al.* 2011). The Grey Water Footprint (GWF) is generally calculated with Equation 2 presented in the WFA manual (Hoekstra *et al.* 2011).

$$GWF = \frac{(\alpha \times Appl)}{\mathrm{Cmax} - \mathrm{Cnat}} \qquad \text{(Eq. 2)}$$

GWF = Gray Water Footprint (m^3/ton)
α = Leaching run-off fraction (constant)
Appl = Applied chemicals (kg/ha)
C_{max} = Ambient water quality standard (kg/m^3)
C_{nat} = Natural concentration in receiving water body (kg/m^3)

Instead of using the more general leaching run-off fraction and applied chemicals method for estimating the GWF, a more detailed model, which is specific for the leaching of the nutrients nitrogen and phosphorous in Finnish soils and for Finnish agricultural practices, has been utilized. The model for Nitrogen (N) has been developed by Grönros (2003). For phosphorous (P), the dissolved and suspended P need to be calculated separately then added together. The calculations for P leaching are based on the model developed by Ekholm *et al.* (2005). The models have been used in the form presented by Saarinen *et al.* (2011); for a more detailed explanation of the model see Appendix I. N as well as dissolved and suspended P are calculated for each individual farmer and replace 'α' and '*Appl*' in the GWF formula. This constant reflects the type of soil and the N and P applied and use by plants for each specific farmer.

Both P and N are naturally occurring vital nutrients for plants in aquatic ecosystems. However, excessive point and non-point input of the nutrients P and N causes unfavorable eutrophication of water bodies (Carpenter *et al.* 1998). Normal P levels have not been proven to have any adverse impacts on humans or animals, which is why no drinking water standards have been set for the nutrient. However, for common safety the maximum daily P intake has in Finland been determined as five grams (National Nutrition Council, 2005). Despite its limited direct impact on humans, excessive P concentrations have indirect health consequences as P stimulates the growth of toxic algae and causes anoxic conditions in water bodies (Carpenter *et al.* 1998). Nitrate and nitrite are toxic to humans in higher concentrations, thus drinking water guidelines have been set by the WHO at 50 mg/l for nitrate and 3 mg/l for nitrite (WHO, 2012), and N is therefore an easier substance to define maximum concentrations for than P.

In lack of universally accepted risk limits for P, it is up to the national environmental agencies to set guidance limits with which to direct stewardship practices. In the WF manual, Hoekstra *et al.* (2011) suggest the use of the so-called 'ambient water quality standard' as the maximum allowable level, a distinct type of water quality standard, which varies in each water body and reflects a concentration which is optimal for maintaining a pristine ecosystem in that particular area. Other WF studies, such as the one conducted by Coca-Cola (2010), use the US Environmental Protection Agency's daily maximum acceptable concentration for N, when calculating their GWF. But as P is not ranked as an acute toxin such as nitrate, P limits are not widely defined.

GWF calculations are generally done only for the critical polluter, because it is assumed that if the critical pollutant is sufficiently diluted, other pollutants have also simultaneously been diluted to a level where the pollutants do not cause any environmental damage. In this study the preliminary analysis which was made for both N and P, showed that P was the critical pollutant in all but one of the analyzed water bodies. Pote *et al.* (1996) also showed that most often P is the nutrient which limits accelerated eutrophication, because several blue-green algae are able to utilize atmospheric N. The rest of this thesis thus views P as the critical pollutant and only includes the calculations made for P in order to properly represent the water pollution level which ensures a good environmental status as well as human wellbeing.

The C_{max} values are in this thesis set according to the target concentrations defined in the Finnish Action Plans for Yläne River and Kokemäki River (Salmi & Kipinä-Salokannel, 2010). The C_{nat} has been calculated according to the current tot-P loads of the watershed, the mean volumetric flows and percentage estimations of the naturally occurring leaching, atmospheric deposition and storm water run-off of the total nutrient flow into the water body (based on the VEPS model and data from VAHTI). However, it is worth noting that defining the exact natural levels before human interference is due to lack of data, close to impossible, and the values used thus only represent best estimates.

3.4. Product water footprint

A product WF is calculated through a stepwise chain and requires knowledge of the different stages in the production. Product WFs reflects the water consumption required in the supply chain and processing of the raw material, including everything from the direct water consumption of the processing to the overhead water use by the personnel and the indirect water use for energy production. The first stage of the production chain is oat cultivation, the second stage is the oat flake production facilities in Nokia, and the third step is the non-dairy production facilities producing the final oat drink product. Figure 2 shows the production chain as well as inputs and outputs of blue, green and grey water in the production of the oat drink.

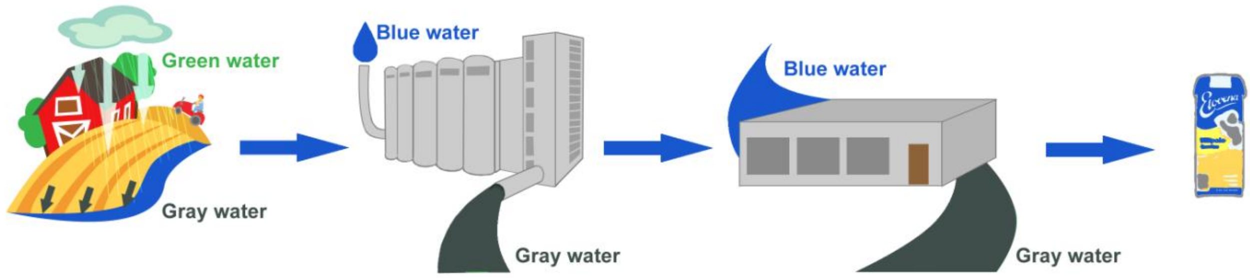

Figure 2 : Illustration drawn to visualize the cradle-to-gate chain and water flow in producing the oat drink

The Nokia factory is located in the Kokemäki watershed, while the non-dairy factory is placed in Turku in southern Finland. The non-dairy factory only produces products with plant-based ingredients, thus the specified name.

3.5. Impact assessment

Even with a well-developed framework, water resources will always be local and have individual internal and external characteristics such as soil, ecosystem and differing activities being undertaken in the watershed, which make them hard to compare to other locations. This is where a WF Impact Assessment (IA) becomes useful, as an IA shows the current sustainability of the operations and thus aggregates the information which has been analyzed previously in the assessment. The IA measures the percentage of the water body's assimilation capacity which is used by the need for dilution of the released pollution. The IA is done after the accounting stage, where an average WF for the production has been calculated, allowing an estimate to be made of the total WF from the performed activities. The theoretical water quantity is then compared to the available water flow in the catchment. It is important to note that everything from the selection of the maximum and natural concentrations for the accounting stage, to the definition of the total assimilation capacity in the IA, needs to be done on the same scale and separately for each watershed. An IA can be estimated for blue, green and grey water, but has in this study only been calculated for blue and grey water as green water is not seen as a scarce or vulnerable resource.

The environmental IA for GWF is made by comparing the GWF with the assimilation capacity of the receiving water body (Hoekstra *et al.* 2011). It is calculated according to Equation 3.

$$WPL\,[x,t] = \frac{\Sigma WF\ [x,t]}{Ract\ [x,t]} \qquad \text{(Eq. 3)}$$

WPL = Water Pollution Level
ΣWF = Water Footprint (m^3/ha)
R_{act} = Actual Run-off (m^3/ha)

The equation gives a percentage of the total assimilation capacity that our farmers have consumed, which can then be compared to other activities in the watershed.

In the BWF IA it is not the water pollution level that is examined, but the water scarcity. Similarly as GWF IA, the BWF IA is done by comparing the BWF of the production with the water extraction site's water availability. The equation looks the same as the GWF above. Substantial use of blue water in water scarce areas will show IA results which indicate that the factory is utilizing a large percentage, or even more than 100% utilization of the total water quantity in the water resource.

3.6. Data and practical limitations

As a quantitative study, the analysis relies on an input of data from different parts of the life cycle of the product. The major part of the data used in the study has been collected by the Raisio Group for their own internal use. Data are compiled from reports made by the contract farmers as a part of the company's efforts to better track the source and quality of the produce. The reporting allows the company to reveal and minimize flaws detected in their food products. It is important for the company to keep track of the origin of their produce as any quality discrepancies immediately affect the quality of the end products, due to the often low number of additional ingredients other than the main cereal component. Contract farmers are asked to report information about the basic characteristics of their farm, as well as on information of their fertilizer and pesticide use. Not all farmers have fulfilled the report criteria standards. Thus many have been excluded from the analysis because of lack of sufficient data. It is also important to note that even if this study attempts to give a more comprehensive picture of the WF of the specified products, the analysis is still limited by a cradle-to-gate approach.

Apart from case study specific information provided by the Raisio Group, data from literature reviews, oral interviews, Finnish environmental agencies and the Finnish Meteorological Institute have also been used in the analysis. Despite time aspects being important when analyzing water resources, this study is made for 2011, mainly because there is solely one cultivation season in Finland and a more detailed time interval would not have contributed to the general understanding of a product's WF.

Because of the close collaboration and exchange of delicate production process information, this study is subject to data enclosure restrictions stipulated in the confidentiality agreement with the Raisio Group. The contract prevents inclusion of more detailed data which has been reported by the contract farmers, such as yields, and nutrient application levels, thus certain defined values in this study are only approximations of the actual figure used in the calculations. Further, some information about the energy use has been excluded from the written report. The most essential data are however included in the thesis to ensure transparency in the methodology and analysis.

When selecting the critical pollutant in this study, the emphasis was on N and P as main components of water pollution and eutrophication. Even though attention was directed towards nutrients, it is important to note that heavy application of pesticides might have a significant impact on water quality. The WF from transport was not taken into account as in this case it does not produce a significant WF; likewise the packaging has not been studied in more detail, and also the fuel used for farming of oats has been excluded. Moreover, the small amount of added ingredients to the final oat drink has not been allocated a WF as they comprise less than 1% of the final product. According to the water footprint manual, components which contribute less than 1% of the footprint can often be left out as they do not significantly impact the final volumetric measure. In this study, environmental disruption caused by thermal heat does not occur and is thus not discussed.

Additionally, the overhead water consumption, originating from the employees water use in the factories, was not possible to separate from the total water consumption in the complexes, because no exact measurements have been made. Thus, the blue water consumption is an overall estimate based on the full water use of the complex and allocated per ton of produced product. This water quantity is thus divided by the total production, including all different kinds of products produced in the complex, which means that the water quantity for the specific oat products might deviate. Unfortunately this inaccuracy cannot be corrected without more detailed data about the water use of the production facilities. Chemicals used in the washing processes of the non-dairy processing factory were not examined because of lack of detailed information about the wastewater pollutant levels, but the water pollutant emissions from the cleaning discharge could be worth more attention in future water quality studies. Similarly nutrient levels of the wastewater originating from the Nokia factory was not possible to examine because of lack of detailed data about the pollutants in the wastewater of the production plant.

Throughout the WF analysis, large issues with truncation are also continuously encountered which increase the uncertainty of the final results. The analysis involves calculating with vast water quantities and minimal nutrient concentrations, leading to high uncertainties in the output. Such issues are likely to be encountered in most WFAs, because of the nature of the assessment.

4. Water footprint case study application

In order to gain insight into the use of the framework; a case study from oat farming and processing in southwestern Finland has been chosen. The work was done in close collaboration with the Raisio Group which provided data and knowledge about oat production in Finland and the processing of the examined oat products. In order to get a detailed insight into the water use, specific watersheds were selected for closer analysis.

4.1. The Raisio Group and an introduction to the case study

The Raisio Group is a Finland-based international company, which specializes in plant-based food and animal feeds. In 2011, the company had a total of 552,6 M€ net sales (Raisio Group Annual Report 2011). The Raisio Group has taken voluntary measures to examine their environmental impacts throughout the operational chain by incorporating a cradle-to-gate approach to their environmental monitoring, impact assessment and product labeling. This includes active work with, for instance, carbon footprint assessment and labeling on their products. For their contract farmers, the Raisio Group has developed the Closed Circuit Cultivation CCC ® concept (hereupon CCC) which aims to measure how well the energy, carbon and nutrients are used in the farming process. The CCC concept includes three different measurement methods; the EcoPlus index which scopes the energy use for cultivation compared to the energy content of the crop, the CarbonPlus which measures the carbon dioxide equivalent emissions from the cultivation, and the WaterPlus which quantifies the nutrient loss to water from farming. Through the CCC concept, the contract farmers can track their own index over the years as well as compare their results with those of other farmers and thus get an overview of their own progress.

In this study only oat production and processing will be examined as a clarifying case study. Oats (*Avena sativa* L.) is an annual grass used widely for human consumption, but the green plant is also excellent for hay and silage, while the grain is an important livestock feed (Suttie, 2000). In temperate regions, oat is mainly spring sown, with a growth period of 94 to 106 days (Kangas, 2011). Oat is a relatively persistent crop which can be grown on soils which are too poor in nutrients or acidic for wheat or on most soils as long as the y have sufficient drainage (Suttie, 2000). In Finland, oats have been a staple on the breakfast table for a long time. Figure 3 shows the changes in oat yield and production from 1961-2010 (FAOSTAT, 2010).

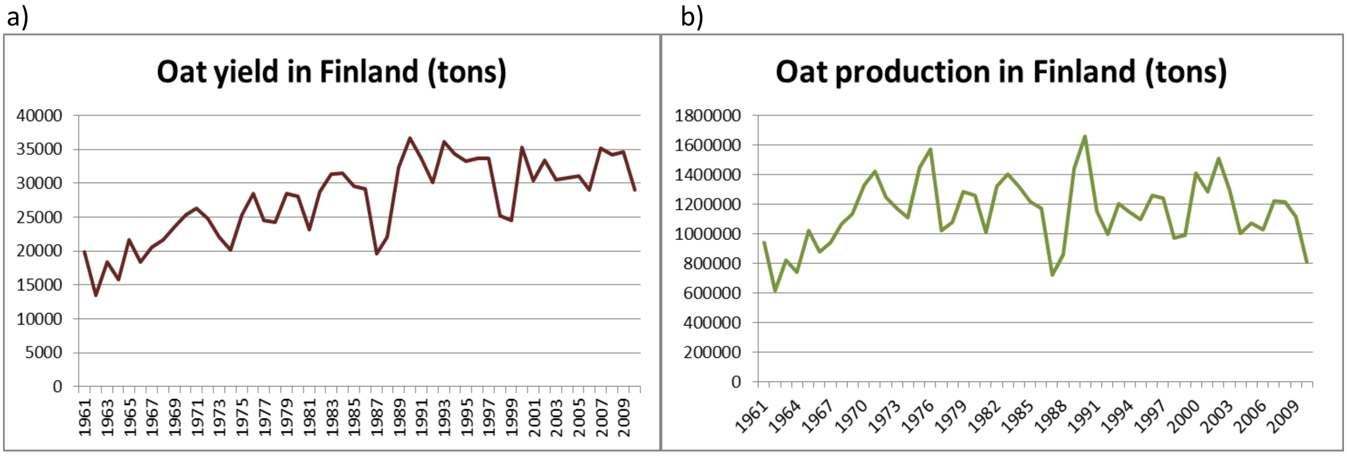

Figure 3: Oat yield (a) and production (b) in Finland 1961-2010 (FAOSTAT, 2010)

The majority of oat farmers delivering oats for processing to the Raisio Group are contract farmers who have signed an agreement with the company to deliver a set quantity and quality of oats, and in return the Raisio Group is obligated to buy the oats which they have agreed upon earlier (Laurinen, personal communication, 2012). A system of dealing first-hand directly with contract farmers, instead of purchasing cereals from a central cereal broker, requires more work from the company’s side, but in return, gives better control and a closer connection with the cereal producers. Direct purchasing from the producers also gives better security both for the farmers and the company as well as improves the ability to track the origin of cereals if necessary. By tracking the origin of the cereals, spread of diseases and other pests can quickly be stopped and the original source pinpointed so that counter-measures can be taken to prevent additional damage. Further, better tracking of the raw ingredients and continuous quality controls ensure a high quality final product, which ultimately is the main concern of the operations.

Water scarcity is not currently an immediate threat in Finland, but the decline in water quality and rising pollution of the Baltic Sea are environmental problems which increasingly need to be addressed (HELCOM, 2011). Measuring the GWF gives a new insight into the water pollution of the production and processing of products and the potential impact this has on the receiving water bodies. Because of the uncertainties in the WFA and the inadequate research that has been directed into examining the GWF, this study was requested by the Raisio Group. This study thus aims for a more detailed investigation of the GWF component of the water footprint framework, applying it to a specific case of oat farming and processing in Finland.

4.2. Selection of watersheds for analysis

Because water resources are spatially explicit, their distribution needs to be mapped before further analyses can be carried out. Previously, the assumption was that the Raisio contract farmers were located close to the oat flake production facilities in Nokia. This assumption was based on the fact that low prices on oats and oat products increase transport costs and can thus dissipate any marginal revenue, which means that the cereals are often bought from areas surrounding the production facilities. By mapping the oat farmers using a geographical information system (GIS), this assumption could be tested and further areas for study selected appropriately on a more coherent basis.

Figure 4 plots the farmers on the map according to which county they are located in. The map shows the approximate spread of the farmers which the Raisio Group buys oats from. Figure 4 also shows the location of the farmers which have reported information that provides sufficient data for the calculations. This visualization already shows some useful patterns of distribution, which allow the selection of hotspots in the watersheds with a clustering of Raisio Group's contract farmers. By using this map, locations can be matched with the total distribution of oat farmers.

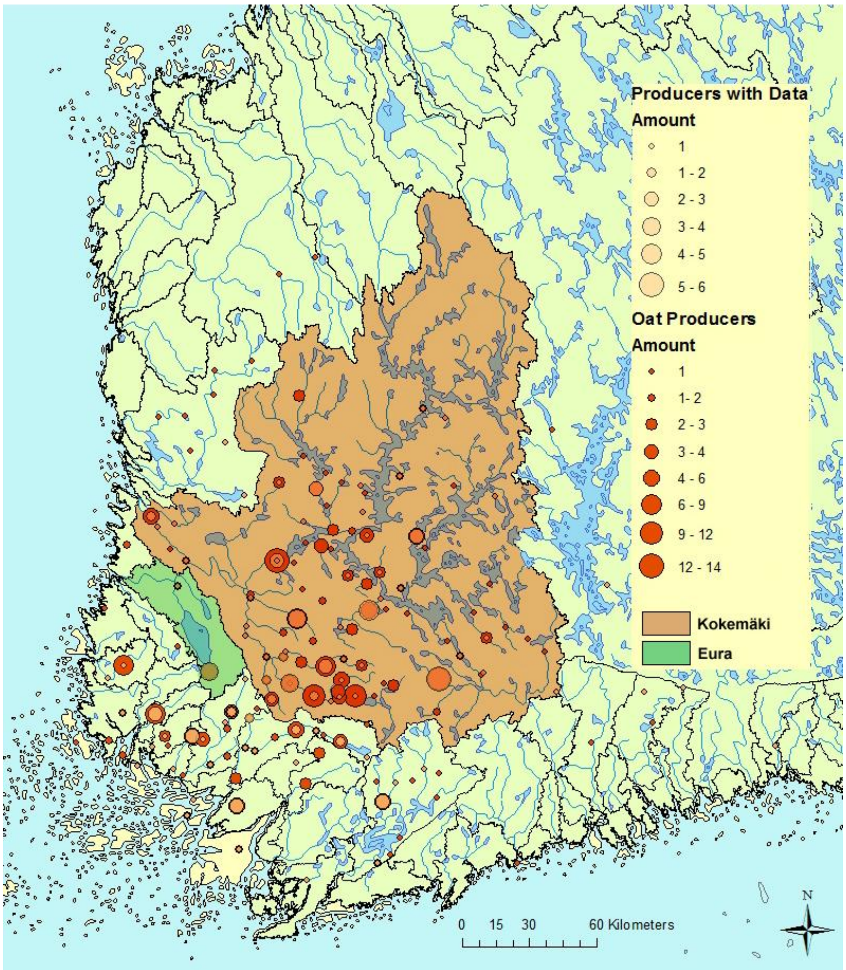

Figure 4: All Raisio oat contract farmers in 2011, producers which have reported sufficient data as well as the watersheds selected for analysis

Based on the map, the Kokemäki and Eura river watershed have been selected for further study. The selected catchments differ in their characteristics, one has a larger lake which affects the nutrient flow (Eura River watershed) and the other is a larger more complex watershed which also contains the vastest number of producers (Kokemäki river watershed). The extent of the selected watersheds is visualized in Figure 4 above by using orange for Kokemäki watershed and green for Eura river watershed.

By using the exact street address information, individual farmers have been plotted on the map with ETRS-TM35FIN coordinates (the main Finnish coordinate system) at a more detailed city or village level according to coordinate data extracted from the service Karttapalvelu (National land survey of Finland, 2011). By plotting the farms on the map at address level, the dispersal of farms can be visualized with better accuracy. More specific data points also allow for identification of the sub-catchment within which the farms are located. This method was chosen for detailed analysis of the Eura River watershed, where the exact position of the farmers was located and the Yläne River selected as the most appropriate sub-catchment to study.

5. Results and Analysis

The following section will present the water footprint accounting stage of the WFA, including calculations of blue, green and grey water footprints. Furthermore, an impact assessment is also made for grey and blue water. All results, if not otherwise stated, are based on data provided by the Raisio Group and their contract farmers.

5.1. Blue water footprint accounting

In this study the BWF is calculated for the water and energy use in the oat flake factory as well as the water and energy used in the non-dairy factory which produces the oat drink product. Due to lack of detailed data on the types of blue water consumed in the factories, the BWF will be calculated according to data of the total water consumed in the complexes. The total water use includes overhead water use in the factories, such as personnel drinking water and water used for hygienic purposes. Further, even though other products are produced in both factories, the water consumption is still based on an average for the whole production, and the individual discrepancies between the different types of products cannot be separated in these calculations.

In 2011 the Nokia oat flake factory reported a water consumption of 0,16 m^3/ton of product. Further, the factory uses on average 162 kWh/ton of electricity and 1,0188 GJ/ton of steam for oat flakes in 2009, adding a WF of 0,1 m^3/GJ and 0,1 m^3/GJ respectively (Alakangas 2000, Gerbens-Leenes *et al.* 2009). The total BWF for the oat flake production is thus 0,36 m^3/ton.

The non-dairy factory reported a water consumption of 17,45 m^3/ton of product in 2011. Including the electricity and heat use, the total BWF for the non-dairy factory amounts to 23,7 m^3/ton (Alakangas 2000, Ecoinvent 2.0 2010, Gerbens-Leenes *et al.* 2009).

5.2. Green water footprint accounting

Table 1 shows the results of the CropWat analysis used in the green WF accounting. The CropWat results seem to indicate that irrigation would be required during the later seasons, but irrigation is, in general, not used in Finland for cereal production because the rainfall is seen to be sufficient for the crops. ET_{green} is calculated as the minimum of total crop evapotranspiration and efficient rainfall.

Table 1 : CropWat results from Jokioinen weather station calculated for the growth period of oats

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.	Etgreen
			coeff	mm/day	mm/dec	mm/dec	mm/dec	mm/dec
May	2,00	Init	0,25	1,12	6,70	9,00	-	6,70
May	3,00	Deve	0,27	1,30	14,30	16,80	-	14,30
Jun	1,00	Deve	0,51	2,61	26,10	17,40	8,70	17,40
Jun	2,00	Deve	0,78	4,26	42,60	18,60	24,00	18,60
Jun	3,00	Deve	1,06	5,33	53,30	25,40	27,90	25,40
Jul	1,00	Mid	1,23	5,64	56,40	37,30	19,10	37,30
Jul	2,00	Mid	1,23	5,24	52,40	45,80	6,60	45,80
Jul	3,00	Late	1,06	4,16	45,80	34,20	11,60	34,20
Aug	1,00	Late	0,61	2,22	22,20	16,00	6,20	16,00
Aug	2,00	Late	0,31	1,04	4,10	1,80	1,90	1,80
			Total:		**323,80**	**222,20**	**106,00**	**217,50**

The green water requirement for oats in Finland in 2011 is thus 217,50 mm/period (dec) or 2175 m^3/ha. The final green WF average is then calculated by dividing the green component with the oat yield reported by the contract farmers. The results show that the green WF is 494 m^3/ton of oats in Kokemäki watershed and 527 m^3/ton for Yläne River.

5.3. Grey water footprint accounting

Yläne river has a total phosphorus nutrient flow of 7 tons/year (Salmi & Kipinä-Salokannel, 2010) and a calculated critical load of 2,6 tons/year, while Kokemäki watershed has an estimated Phosphorus (P) nutrient flow of 337 tons/year (Salmi & Kipinä-Salokannel, 2010) and thus a critical load of 230 tons/year. Both watersheds exceed their critical load, which is reflected by the less than satisfactory P concentrations in the water bodies. In the WF calculations, the critical load is presented in the form of a water volume, thus if the Raisio oat farmers would be releasing the same quantities of P as the critical load their GWF total would be equal to the total water flow in the analyzed watershed. The GWF illustrates a hypothetical virtual water quantity which aims to represent the degree of water pollution in the watershed. To define the GWF natural nutrient concentrations, ambient water quality standards and leaching fractions or models need to be selected for the critical pollutant. However, the parameters are not clearly defined in the WFA manual and the selection of appropriate limits and models is thus up to the practitioner.

5.3.1. The selection of the leaching run-off model, results and analysis

The GWF calculations require knowledge and input of the applied nutrients or chemicals and the proportion of these which has leached to adjacent water bodies. Applied nutrients for farming equals the amount of dissolved P used on the field, which farmers often have quite good knowledge of, and are able to report on. However, the leaching run-off fraction is not as straight forward, as it involves knowledge of how nutrients react in the soil and how they are transported along the water pathways. The leaching of nutrients depends on several factors, such as retention, slope, soil characteristics and more; it is thus difficult to accurately model nutrient flows from field to watershed. Increased P content in the soil raises the P loss to surface waters; thus continuous excess application of fertilizers raises the P concentration in freshwater bodies (Pote *et al.* 1996). The loss occurs in both dissolved and particulate form. The spatially explicit and complex nature of nutrient leaching and run-off makes it difficult to make accurate generalizations which would adequately reflect reality, thus the selection of the model which is utilized in the calculations can have a considerable impact on the final GWF. Table 2 shows the average GWF for a ton of oats produced in the Kokemäki watershed, first with the Finnish leaching model and secondly with a specified fraction range from 0.5-2% runoff loss as used in Dabrowski *et al.* (2009).

Table 2 : Differences in GWF for a ton of oats depending on whether the Finnish leaching model or a more general leaching runoff fraction is used (m^3/ton)

	Finnish leaching model	General 0.5% runoff loss	General 2% runoff loss
Kokemäki	3995	489	1954

5.3.2. The selection of thresholds, results and analysis of the results

In an attempt to address the difficulties with selecting natural and maximum concentrations, the Water Footprint Network gathered an expert group for a GWF workshop to clarify some issues and areas which critically require further research. Amongst the topics for the workshop was the lack of data for defining the C_{max} and C_{nat}. The Water Footprint Network GWF working groups stated in their workshop report (Zarate, 2010) that natural nutrient concentrations cannot be based on values defined according to the EU Water Framework Directive (WFD) as these already presume a certain level of human impact on the water body. However the EU WFD Action Plans provide the most detailed reports about the state of the Finnish water bodies available and give clear target nutrient concentrations to aim for; thus, in lack of separately defined and applicable ambient water quality standards, the target concentrations defined in the Finnish Action Plans for 'good' ecological status have been chosen as the maximum concentrations in the GWF calculations presented in this paper.

The EU WFD (2000) was established to create an integrated community policy on water, in order to secure safe drinking water and protect the environmental status of water resources within the union. The goal of the EU WFD is to reach 'good' ecological status in all EU water bodies. The WFD has five classification statuses for water bodies and defines the highest statues as: " *'High status' is defined as the biological, chemical and morphological conditions associated with no or very low human pressure. This is also called the 'reference condition' as it is the best status achievable - the benchmark. These reference conditions are type-specific, so they are different for different types of rivers, lakes or coastal waters so as to take into account the broad diversity of ecological regions in Europe.*" (EU, 2012). The 'good' status is thus a 'slight deviation' from the high status (EU, 2012). Effort has however been put forth to intercalibrate and define the statuses more accurately to ensure coherency throughout the EU.

The large variation in different sources from which maximum and natural concentrations can be selected poses considerable difficulties for practitioners in the private sphere, where resources are not always available for in depth analysis. Table 3 shows the calculated C_{max} and C_{nat} for the different watersheds which are based on the values given in the EU WFD Action Plans for watersheds in southwestern Finland (Salmi & Kipinä-Salokannel, 2010). More complete examples of calculations can be seen in Appendix I and II.

Table 3 : Calculated P C_{nat} and C_{max} for the selected watersheds (kg/m^3, based on Salmi & Kipinä-Salokannel, 2010)

	Yläne river	Lake Pyhäjärvi	Eura river	Kokemäki river
C_{nat}	0.000021	0.0000060	0.0000070	0.0000015
C_{max}	0.000060	0.000018	0.000060	0.000035

Methodology for selection of C_{max} and C_{nat} used in this study has not been used in any previous WFAs; thus to illustrate the difference between the selected critical values and those used or suggested by others, some alternative C_{max} and C_{nat} values have been compiled. In an oral interview with the water expert Bilaletdin at the Pirkanmaa Centre for Economic Development, Transport and the Environment (2012), the natural concentration of P was stated as usually being around 20 µg/l for water bodies; this is a natural concentration which is significantly higher than the ones calculated for the different catchments. Another alternative was presented by the WF expert Jesse Rep at the wood processing company UPM. The C_{max} used in their calculations is the current concentration of the critical pollutant, with the justification that UPM is not responsible for cleaning up the water body, but simply wants to ensure that further degradation does not occur. In the WF calculations done by UPM (2011) the C_{nat} and C_{max} were defined according to German local authorities for the UPM Nordland water catchment and set at 0,05 (C_{nat}) respectively 0,3 mg/l (C_{max}), and the same values were also used for factories in Finland. The study by Liu *et al.* (2012) of the world river's GWF defines the C_{nat} as 0,52 mg/l according to Meybeck (1982) and calculations done with the Global *NEWS* model. The C_{max} in the study by Liu *et al.* (2012) is based on national surface water quality standards gathered from literature and set at 0,95 mg/l. Enumerative C_{max} and C_{nat} do not give much information without putting them into context; thus Table 4 shows averages of the oat farmers' GWF with different selected C_{max} and C_{nat}.

Table 4 : Weighted averages of GWF from Kokemäki and Yläne river farmers using different C_{nat} and C_{max}

	GWF (m^3/ton of oats)
Our calculations	3996
Bilaletdin 2012	8883
UPM 2011	540
Liu *et al.* 2012	310

Even though the same data and leaching model have been used, the differences in C_{max} and C_{nat} produce considerable variation in the final GWF for one ton of oats. As the C_{max} and C_{nat} can be so critical in the calculations, it would be imperative to set a standard for the used parameters. With the current methodology the selection of these critical values is completely up to the practitioner and the end results can thus be influenced and even manipulated to a high extent.

5.3.3. A detailed view of the Eura river watershed as an example

During the selection process, a few watersheds were selected for more detailed investigation. The results of the study showed considerable differences in results between the different water bodies, depending on the differences in hydrology. Figure 5 exemplifies the complexity which can occur within a delineated watershed area, the Eura river watershed. The oat farmers are located in the upper part of the watershed around Yläne River. Throughout the watershed, the P and N concentrations vary significantly (Salmi & Kipinä-Salokannel, 2010). The Yläne River contributes a significant portion of the total incoming nutrient pollution to the nutrient rich Lake Pyhäjärvi, but only low concentrations of P and N leave the lake through the Kauttua rapids.

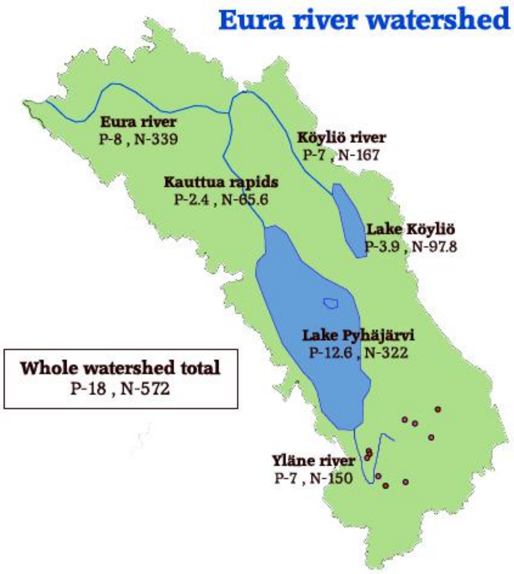

Figure 5 : Variations in the total annual nutrient flows of phosphorus and nitrogen within the Eura river watershed in tons (Salmi & Kipinä-Salokannel, 2010)

In this example the aim is to illustrate how different the C_{max} and C_{nat} can be by calculating according to defined levels in the different rivers and lakes in the watershed. The C_{nat} has been calculated by using the current P concentration in the water body, the mean volumetric flow rate of the water body as well as the defined percentage of the total nutrients which come from natural run-off, atmospheric deposition and storm water (Salmi & Kipinä-Salokannel, 2010). C_{max} is defined according to the target rate which is given for the specific watershed in the Action Plan for 2015 by the Finland Proper Centre for Economic Development, Transport and the Environment (Salmi & Kipinä-Salokannel, 2010). For Lake Pyhäjärvi the C_{nat} was calculated according to the concentration of nutrients (µg/l) and not by using a mean volumetric flow. Appendix II shows the sample calculations from the Yläne river watershed to illustrate the method used. Table 5 shows the calculated GWF for the four farmers which are plotted in the Eura watershed and for which sufficient data exist. Table 5 also shows how large the variation can be just because of the divergence in maximum and natural concentration factors which occurs within a watershed. Interesting to note is that Eura River is the only one of the studied watersheds where N was noted to be the critical nutrient, while the other water bodies clearly have P as the critical factor.

Table 5 : GWF in m^3/t of oats for different farmers in the Eura catchment area, calculated using values from different parts of the watershed

Farmer	Yläne river	Lake Pyhäjärvi	Eura river
1	4658	15043	3427
2	3149	10170	2317
3	4284	13835	3151
4	3998	12910	2941

Lake Pyhäjärvi shows a significantly larger GWF because of the mass of nutrients which have accumulated in the lake. However, despite the large GWF the lake has shown a natural high retention of P, leading to low release of P to downstream water bodies (Ekholm *et al.* 1997). Such natural variations between different water body characteristics provide additional difficulties when estimating the true impact of water pollution. Table 5 shows the differences in GWF which can occur within a single watershed; Yläne River was however selected as the most representative for the calculations presented in this paper as it is the closest water body to the farmers.

As mentioned earlier, P is in this study assumed to be the critical pollutant, however; the preliminary calculations with both P and N showed a divergence when it came to Eura River, where N seemed to require more dilution than P indicating that N would be the critical pollutant. This raises another question, whether or not each watershed should be evaluated separately to determine its critical pollutant? All such additional problematic aspects add to the complexity surrounding GWF and make it stepwise harder to determine which the appropriate constants are that should be used in the calculations.

5.4. Product water footprint

The reasoning behind calculating product WFs is to give consumers more information on which they can base their consumption choices. By calculating a WF for specific products, it is possible to get more information about the water externalities connected with the production of said products. The following chapter thus studies two oat products produced by the Raisio Group based on the calculated WFs for oats produced in southwestern Finland. The calculations are based on information provided through communication with the Raisio Group about the different stages in the process chain of the production.

5.4.1. Oat flakes

Of 1000kg of oats which arrive at the Nokia factory 53,3% reaches the final oat flakes product. The loss along the process is mainly caused by the separation of smaller sized oat grains from the larger ones and the de-hulling of the grains, as only the oat core is used for oat flake production. There is also some general loss along the production chain. The waste products are used for animal feed and bioenergy, but because the process is run with the oat flakes as the main interest 94% of the oat's water footprint should be allocated to the final product's water footprint. The allocation is based on an economic evaluation of the worth of the output product compared to the by-products. The reasoning behind the economic allocation is that oat by-products are utilized simply to minimize financial loss, but are in no way as valuable as the oat flakes and the whole process is only run in order to produce the main product of oat flakes. If looking simply at the amount of oats which is used in production of the oat flakes and directly subtract the water footprint for the waste products, there would be an unfair reduction in the final footprint, as a large part of the footprint would be reduced solely because of the utilization of the by-products.

The results show that the weighted average, based on Yläne and Kokemäki watershed, of the water footprint for the oat flakes would be 7918 m^3/ton, which would translate to an immense 7918 liters of virtual water for 1 kg of the product. The WF for oat flakes consists to 89% of the GWF of oat production. The study by Mekonnen and Hoekstra (2011) calculates the WF for rolled or flaked oats as 2416 m^3/ton, a result considerably smaller than the WF calculated with our parameters.

5.4.2. Oat drink

The oat flakes are used as the base for the oat drink. In the non-dairy production facility the oat flakes are processed, and water is added. Some of the oat flake mass is lost to okara (unusable portion of the oat which becomes a byproduct in the process), which is removed by decanting. At the end of the process chain, some flavoring and other ingredients are added to the oat drink base. Similarly, as in the Nokia factory, an allocation based on the economic value of byproducts has been made, where the oat drink is allocated 97,7% of the water footprint.

The results show that the weighted average, based on Yläne and Kokemäki watersheds, for the water footprint of the oat drink would be 982 m^3/ton of oat drink, or 98,2 liters of water for 100 g of the product. Once again the GWF of the oat production contributes a significant 87% of the final WF even though there is only 10% dry matter in the drink and despite the fact that the non-dairy factory consumes a considerable amount of blue water in their cleaning processes.

Because these calculations are based on different critical parameters and use a runoff model which is specific to Finland, the end results are difficult to compare to previous studies. Mekonnen and Hoekstra's study (2011) calculate and compare the WF of different agricultural crops and their derived products, concluding that oats on average use 1788 m^3 of water per produced ton, calculated as a global average. Our calculations show that a ton of oats on average uses 4492 m^3 of water, which is over two times as much as in the study by Mekonnen and Hoekstra (2011). If Mekonnen and Hoekstra's (2011) calculated WF for oat flakes (2416 m^3/ton) would be used in the same oat drink calculations, the drink's water footprint would only be 292 m^3/ton compared to 982 m^3/ton in our calculations. This difference is due to discrepancies in the selection of critical nutrient limits and leaching models.

As few product WF studies have calculated the GWF, especially not with the method that has been chosen in this study, it is difficult to compare the results and determine whether the WF results for the oat flakes and oat drink are large or small. In the future, if more studies are done with a clear guideline for selecting the critical parameters, products can potentially be compared with each other in order for consumers or stakeholders to make better informed decisions. The impact assessment however better displays how substantial the WF is, as it compares the calculated water volume with the water availability in the watershed.

5.5. Assessing the impact of the water use

The Impact Assessment (IA) links the water footprint back to the water's original source; it shows how sustainable the water use is at the moment and reflects the degree of damage that is being done. Without doing an IA, the water footprint remains an abstract virtual water volume, which does not relate to an actual resource. An IA can reflect the current status of the watershed, by illustrating the total assimilation capacity of the water body in relation to the current water consumption and pollution.

5.5.1. Grey water footprint impact assessment

The large Kokemäki watershed contains the majority of Raisio's oat farmers and is thus of special interest. Out of around 400 unique farmers, about 220 reside in the Kokemäki watershed with a total yield of approximately 15000 tons of oats in 2011. The IA however shows that the oat farmers would be utilizing only 0,9% of the Kokemäki watershed's assimilation capacity. For Yläne River, about 10 oat farmers have a reported amount of approximately 430 tons of delivered oat. The IA shows that the oat farmers utilize 2,6% of the watershed's assimilation capacity.

These results show a very low impact of the farming on the freshwater resources, meaning the Raisio contract farmers only consume a small fraction of the watershed's total assimilation capacity. The results indicate that despite the nutrient leaching, the water body can still assimilate more nutrients without causing any catastrophic environmental damage. It is important to note that the calculations only reflect the impact of the oat producing contract farmers of the Raisio Group, and do not reflect the whole impact of all agricultural activity in the watershed, nor does it reflect the total impact of all anthropogenic activity in the water body. The results however do indicate that the nutrient leaching from the Raisio contract farmers does not exceed the natural assimilation capacity of the water body.

5.5.2. An alternative Grey Water Footprint Impact Assessment method

If used as such, the current IA does not provide feedback or illustrate how much of the assimilation capacity has already been used. Because of this drawback, this study suggests an alternative approach where the IA is done with a hypothetical, virtual water quantity which changes with the deterioration of the receiving water body's water quality. The suggested allocable water quantity is calculated with the model in Equation 4.

$$Allocatable\ water\ quantity\ \left(\frac{m^3}{year}\right) = \frac{Desired\ state\ \left(\frac{kg}{m^3}\right)}{Current\ state\ \left(\frac{kg}{m^3}\right)}\ x\ Current\ water\ flow\ \left(\frac{m^3}{year}\right) \qquad \text{(Eq. 4)}$$

The critical load is the total amount of a pollutant which can be released to the water body without any environmental deterioration. Critical loads can be calculated by multiplying the total water flow with the difference between the target and background nutrient concentration for the selected watershed. Yläne has a critical P load of 2,6 tons/year, while Kokemäki watershed has a critical load of 230,4 tons/year. Similarly, current nutrient loads can be calculated to assess the current status of the water body. Yläne River's current nutrient content is 7 tons/year, while Kokemäki River's is 337 tons/year. Both rivers clearly have nutrient levels above the ideal; thus it is safe to assume that a portion of their assimilation capacity is already being used.

When calculating the GWF, the natural concentration is subtracted from the maximum allowable concentration, reflecting the allocable water quality which can be used to dilute discharged pollutants. This allocable portion determines the excess of nutrients which can be released to the environment, but does not immediately reflect the current status of the water body. The discrepancies between critical load and current nutrient release illustrate that a fair IA should assume that a certain portion of the water body's assimilation capacity has already been used. To account for this already deteriorated water status, this information should be included in the IA calculations, so that it is possible to get a clearer feedback from the water body when changes in water status appear. By dividing the desired state with the current state, a proportion between these two can be determined; thus if the current pollutant status would be ideal, the result would be one. By multiplying this proportion with the total water flow of the catchment or watershed, it is possible to estimate a hypothetical virtual water quantity which illustrates the clean water available for dilution of pollutants. Therefore, a more polluted water body would have a lower volume of water to use for dilution, while a clean water body could even have a larger hypothetical water quantity than the actual physical water flow. As the WF is already a measure of a virtual water quantity, it should be acceptable to use hypothetical volumes for comparison, as these are still based on the data from the real water resource.

A problem with this suggested method lies in some unfortunate difficulties with double-counting, as the nutrients released by the farmers are already included in the current pollutant load to the water body. It is difficult to separate the nutrient release from the contract farmers from the total nutrient run-off. In this study the double counting is negligible and lack of data does not allow for a better separation of the total nutrient load from agriculture and the total nutrient runoff from the specific farmers. In future studies where better data are available this problem can be avoided by adjusting the calculations through separating the pollutant release from the total release in the watershed.

The results of the adjusted IA do not deviate much from the results of the IA suggested by the manual (Hoekstra, 2011), but these results can vary much more over time and better illustrate trends in water pollution as they incorporate a feature of feedback from the watershed. Table 6 shows a comparison of the results from both IAs.

Table 6 : GWF IA's based on critical loads of Yläne and Kokemäki watersheds (%)

	WF manual IA	Adjusted IA
Yläne	2,6	7,1
Kokemäki	0,9	1,2

In this thesis it has been assumed that GWF is calculated on basis of the concept of critical loads which as discussed earlier is the basis for the GWF accounting methodology. However, the Finnish surface water action plans for 2015, which are made in accordance with the EU WFD, report their nutrient targets in µg/l and have set targets both for the immediate future and a more long term perspective. These reduction targets can also be used in the adjusted IA and are here included to provide a comparison with the critical load calculations. The Yläne River watershed reduction target is much higher for year 2015 (85 µg/l) than what the final water quality target is (60 µg/l), which is reflected in the changes in the IA. For Kokemäki River watershed however the short- and long term targets are the same, as in such a large watershed even the reduction of 1 µg/l requires a significant effort to achieve. Table 7 shows the results of the IA calculations based on the adjusted model for the IA.

Table 7 : GWF IA results with different nutrient targets (%)

	Critical load	Final target	Target 2015
Yläne	7,1	4,3	3,0
Kokemäki	1,2	0,9	0,9

This sensitivity analysis thus shows that even in the IA stage, decisions have to be made which can alter the final results. It is however to be assumed that the critical load concept should be used throughout the whole WFA to ensure congruity.

5.5.3. Blue water footprint impact assessment

As mentioned earlier, Finland is not a particularly water scarce country; thus as expected, even if calculating with the total water use of the factory, which includes other products than just those studied, the impact still seems to be minimal. In this case the Nokia water comes from the Maatialanharju ridge (Ränkman, 2010), where water is produced both naturally and artificially by extraction from Lake Vihnus, while the non-dairy facility uses the Turku city pipeline water from Aura River (Finland Proper Environmental Centre, average for 1980-2005). The Nokia factory utilizes only 0,06% of the available water for its total yearly production, while the non-dairy facility utilizes 0,04% of the available water.

6. Discussion

The analysis and results display large uncertainties in the WF accounting and IA, where certain crucial parameters vastly influence the final volumetric output. These types of issues in the WFA methodology make results difficult to compare and reduces the trustworthiness of the WF as an indicator. However, the framework takes crucial first steps towards quantifying the comprehensive impact our food production has on the earth's freshwater resources, especially showing the impact of diffuse water pollution. Indicators like the WFA are needed in order to visualize the externalities embedded in food trade flows and improve water stewardship.

6.1. The company's strategic decisions and defining sustainability

The selection of parameters such as the maximum and natural concentrations, as well as chosen runoff models, has considerable impacts on the GWF and final WF. Thus the company's strategic decisions can clearly influence the final result of the WF calculations. If choosing a compliance strategy which makes no attempts at improving the water quality, then the maximum concentration can be set at the current pollutant level, resulting in a skewed, but low final WF result. However, if the framework is used in an attempt to comply with high standard environmental regulations and use best available models to select the underlying parameters, such as C_{max} and C_{nat}, the end result will most probably be an absurdly large quantity of virtual water. The selection of the critical parameters and the method with which these are used can vary to such an extent that WF, even within the same industry, can become meaningless to compare. Calculating ambient water quality standards as well as natural concentrations are difficult and labor intensive processes; thus these definitions are seldom available at the necessary resolution for an in depth GWF analysis. These difficulties showcase the necessity of future work with standardization of the methodology and clear guidelines for practitioners. But without clearly defined local ambient water quality standards, even a coherent methodology will not suffice, as the selection of these parameters has such a considerable impact on the final WF.

Without a concise definition of the standards that should be used, the manual guidelines can be interpreted in whichever way the practitioner wishes to. As the company's own definition of sustainability has a heavy influence on the parameters used in the WF assessment, the WF network needs to take a clearer stance in the manual as to which standards are acceptable and which are not. This also includes giving the WF manual users a clear stance in regards to the definition of sustainability the WF network wants to convey and represent. Currently the manual just presents an "*inventory of options"* to guide practitioners into responsible use of the framework (Hoekstra *et al.* 2011, pp. 99). Further, when it comes to water stewardship, there is a need to move beyond just quantifying environmental impacts towards including also the social foundations. This includes recognizing the social impact that low availability or poor water quality can have on depriving people of their basic human needs. To move from a weak sustainability into a stronger sustainability perspective would require reevaluating basic notions in virtual water trading and acknowledging, on one hand, that water scarce areas need to address their consumption side of water use, and on the other, recognize that water quality might also lower human wellbeing and is an essential concern in water stewardship. The WFA Manual (Hoekstra *et al.* 2011) still leaves much room for a company to select their own pathway, whether it is only compliance or if it reaches out into a more proactive attempt to improve water availability and quality. The manual is presently mainly concerned with environmental consequences of water use while social aspects, especially those of justice, are in accordance with the ecological modernization pathway, not amongst the most critical issues. If industry and other actors continue to use the WF framework loosely, with varying definitions of sustainability and degrees of engagement to improve water stewardship, and report results where questionable parameters have been used, the WFA stands the risk of becoming watered down and labeled as a greenwashing framework.

If clear goals have been set at the beginning of the WFA and guidelines for the selected WF methodology used have been defined, the WF framework can serve as a useful indicator in the agri-food sector. However, notable is that the indicator is perhaps best suitable only for internal evaluation, as currently the standardization process is not completed, and the WF is difficult to communicate to outside stakeholders. If the results from the calculations are to be released to stakeholders, then the underlying assumptions need to be clearly defined. But communicating the true meaning of the WFA remains challenging, as even the underlying virtual water concept is relatively unknown to stakeholders who are not familiar with water stewardship and the debate surrounding water issues.

6.2. Water Footprint Assessment as a framework to show trends

The WFA has been developed as a framework with which water quantity and quality can be comprehensively measured, and as such is thus a useful indicator in water stewardship. In decision making it is important to be able to follow the changes which occur in water use and quality in order to make good risk alleviation strategies. As such, the WFA can serve as an indicator to show trends which allows for continuous follow up of the company's water use and its impact on water bodies. There are however some considerations required when selecting the WFA as a framework for improved water stewardship.

If the WFA framework is to be used as an indicator for changes in water resource use, the methodology needs to be replicable. With a clearly defined methodology, the changes in water flow and nutrient concentrations can be modeled even at a more detailed time scale. If the defined methodology is used throughout, the results will also be comparable on a yearly basis, allowing for the use of the framework to indicate trends. The suggested divergent IA methodology should further improve the framework's ability to showcase changing trends in water quality and pollutant emissions from the cultivated fields.

The spatial scale can pose some difficulty when replicating the study, as the delineation of the case study can vary depending on the data availability and the work effort put into the assessment. The vastly varying sizes and types of water bodies in the watersheds present a number of different difficulties when choosing the maximum and natural concentrations of nutrients and highly affect the outcome of the volumetric water footprint. Even though this study is focused on grey water, it is important to note that also blue and green water accounting suffers from the impediments which these problematic differences in watershed characteristics present. These obstacles can be overcome by clearly defining the aims of the study and from the onset, specifying the level at which the whole analysis will be done. Further, visualizing the watershed provides valuable new information, as plotting the activities of the company on a map, and showing the extent and manifold of variety in the types of water bodies within the catchment, it is possible to get an insight into the complications which may occur when modeling the water and nutrient flows.

The Yläne River case study provides a detailed look at a specific watershed and allows for calculations with nutrient levels and water flow for the catchment area closest to the selected farmers. But it is not practical and is too time consuming to define the closest water body for all 370 oat farmers there is sufficient operational data from, let alone the over 2000 farmers which the Raisio Group buys cereals from. There is thus a need to generalize when attempting to create practical guidelines, but because of the changes in nutrient levels throughout the watershed, the average natural concentration and ambient water quality standards will be difficult to define. Calculating with nutrient level of the whole watershed will cause an overestimation of the nutrient concentrations and is problematic when defining the mean volumetric flow rate. Using the values for downstream Eura River instead fails to reflect the retention of nutrients in Lake Pyhäjärvi. The same kind of difficulties are encountered by other larger food producing companies, as they all deal with a multitude of suppliers which all have activities in various watersheds. It is thus once again necessary to clearly justify and clarify the decisions made throughout the analysis, as well as to follow a certain chosen strategy through the whole assessment. It is thus essential for companies to get clear directions on how to select their constants without simplifying to the extent where the final outcome no longer reflects the reality.

Several difficulties have already been discussed throughout this thesis. Because of the still ongoing standardization process of the GWF assessment, the analysis is difficult to complete and requires a considerable work input and knowledge base from the practitioner's side. Expert opinions are needed for selecting parameters, as these are not defined in a clear manner in the WF manual. Further, the need for detailed spatial analysis requires some knowledge of modeling and geographic information systems, which perhaps is not always available. For detailed spatial analysis, there is a need for watershed maps of the selected case study areas, and depending on the selected resolution, these maps can be difficult to acquire. The data requirements in the calculations are, depending on the resolution the analysis is done, relatively high, as especially the yield and nutrient application on field level are essential inputs. The data needs to be collected from farmers, who need to be willing to disclose detailed information about their yields and agricultural practices, such as fertilizer and pesticide use. The most prominent difficulty however lies in the fact that the practitioner initially needs to have an understanding of water cycle dynamics and nutrient flows, as well as a basic comprehension of modeling, nutrient and yield calculations. However, if the methodology is clearly defined and the models well prepared, future practitioners can use built models to simply input updated data and easily get new results. Once the initial drawbacks of the WF framework have been sorted out, it has potential to become a usable indicator within the private industrial sector, presumptively if data are available from their own supply chain.

6.3. The water footprint assessment and water stewardship in the agri-food sector

As pointed out earlier, there are several methodological and practical difficulties connected to the WFA, but the framework also provides valuable information which can be used to improve water stewardship in the agri-food sector. A WFA can provide a detailed insight into the different types of water use and impact the consumption has on the water resource. Instead of simply examining direct water use, the WFA separates different water resources and types of water use from each other, allowing for an impact assessment of different components. For example, even if the green water use is sustainable, the blue and grey water use might have an impact on the water resource. Further, the analysis also does a spatial breakdown of the different water resources, which is important when studying a geographically confined resource such as water, as it allows for an evaluation of the impact of each farmer, watershed and industrial complex separately if desired. Water pollution and the grey water component have previously not been studied in much detail, but these are an integral part of water stewardship as degraded chemical status can push the water body out of equilibrium and permanently alter its ecosystems, which in turn lowers human wellbeing. In the agri-food sector the cultivation is a significant constituent of the final WF and stands for a large share of the direct water consumption as well as the water pollution. Further, in agriculture, diffuse nutrient leaching is a major problem which needs to be resolved. This study has illustrated the necessity of studying the grey water component of the WFA in more detail, as quantifying diffuse runoff and illustrating its impact on the receiving water body is an important component of sustainable water stewardship in the agri-food sector. The WFA framework can aid with finding hotspots where direct water consumption is unsustainable from a water availability point of view, but this study also illustrates that the water pollution can sometimes create a more significant impact than the actual water extraction, and that especially in the agri-food sector this water pollution might be worth more attention in order to avoid pushing water ecosystem permanently out of balance and endangering the future of the water resource. Thus, the WFA does not only point out hotspots where direct water extraction is an issue, it also shows in which areas water pollution is a more significant issue. By examining different types of water use and issues under one single framework, it is possible to comprehensively compare different locations and activities, in order to select the best pathway towards sustainable water stewardship. Finally, the last step of the WFA is formulating a response strategy; this strategy should be done on the basis of a solid trustworthy assessment in order for the selected actions to serve in the best interest of the company and the health of the water resource.

7. Conclusion

This thesis has examined the WFA framework, especially the grey water component, and discussed its value for water stewardship in the agri-food sector. The study revealed several uncertainties in the methodology which need to be resolved, but also shows the importance of examining not only direct water consumption, but also diffuse water pollution as an integral component of water stewardship. Below are the main findings of this study:

- If GWF is to be used worldwide in the agri-food sector, it is crucial to define and standardize the selection of C_{max} and C_{nat}. Without standardization current GWF results are impossible to compare; thus benchmarking becomes onerous. As the leaching and run-off of nutrients can vary considerably with factors such as slope, precipitation and soil, losses of P or other nutrients from fields needs to be modeled to receive a more detailed overview and knowledge of the water consumption. The selection of leaching model should be done according to best available knowledge; preferably the manual should thus suggest reliable and preferable models to be used. Alternatively, if a simplistic leaching run-off fraction is to be used the fraction needs to be standardized to make different GWF studies comparable.

- Current suggested GWF IA methodology poorly showcases a change in the assimilative capacity of the receiving water body. The feedback from degraded water quality can be incorporated by subtracting the already used assimilation capacity from the total water quantity in the watershed, and thus use an allocable virtual water quantity which reflects the remaining assimilation capacity of the water body instead of the total water flow. In this way it is possible to get a more reliable IA, which clearly reflects the changes in assimilation capacity of the water resource.

- If the parameters and methodology used are clearly defined, the WFA can be used as an internal indicator to show trends in water use. However, the results are difficult to communicate to external stakeholders, especially those which do not have an insight into water stewardship. By separating different types of water consumption and impacts of the water use, it is possible to acquire more detailed knowledge about the water resource, and thus accurately tailor the water stewardship strategy to ensure more sustainable water use.

This study focused on the impact of diffuse phosphorus pollution from agriculture and product WF of two agri-food products. In the future it could prove interesting to also study the impact of diffuse leaching of pesticides, in order to determine if certain pesticides might in fact be the critical pollutants which need to be examined in the GWF accounting. Moreover, research should attempt to provide the private sector with a standardized methodology to allow for benchmarking of products and in order for the assessment to become more useful in external communication and not only as an internal indicator.

Another important aspect of water resources is the uncertainty which climate change poses on future water availability and quality. Future research is needed to determine the potential impact climate change might have, in order to predict future trends more accurately.

Alternatives to the WFA have been developed to address the issues presented above, such as the revised WF approach which links blue and green WF to a water stress index done by Ridoutt and Pfister's (2010), as well as promising advances by the Alliance of Water Stewardship in developing a comprehensive water stewardship standard for certification. However, these alternative approaches are still under development and have not been put to practice as much as the WFA framework. As water issues are continuously receiving more attention, the research is also rapidly advancing and the WFA needs to keep up with the new developments and adapt to changes, as well as continue to solidify the methodology in order to improve the credibility of the framework.

Without a coherent and clear methodology, there is no stable knowledge base on which to ground reliable long-term water stewardship decisions. The last step of the WFA is formulating a response strategy, but before this phase becomes relevant, the analytical base on which the decisions are made needs to be strong enough to support relevant decisions. This includes an understanding of the types if water used, as well as knowing whether the utilized water resource is currently facing or at risk of running into scarcity or water pollution issues. Through pinpointing the problem areas where the freshwater resource is being used in an environmentally unsustainable manner and connecting this information to the broader societal perspective, it is possible to extract useful knowledge for better comprehensive water stewardship. The WFA shows promising steps towards a more inclusive water assessment framework, but still needs further research for it to become a permanent fixture for water stewardship practitioners and decision makers.

References

Alakangas, E. 2000: *Suomessa käytettävien polttoaineiden ominaisuuksia* [Properties of fuels used in Finland]. Technical Research Centre of Finland, Espoo. VTT tiedotteita – research notes 2045, 172 p.

Allan, J.A. 1993: *Fortunately there are Substitutes for Water Otherwise our Hydro-political Futures would be Impossible*. In Priorities for Water Resources Allocation and Management. London, United Kingdom: ODA: 13–26.

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, Rome.

Alliance of Water Stewardship: http://www.allianceforwaterstewardship.org/ accessed on 11.05.2012

Barton, B. 2010: *Murky waters? Corporate Reporting on Water Risk: A Benchmarking Study of 100 Companies.* Ceres, Boston, February 2010.

Barrett, C. B. 1996: *Fairness, stewardship and sustainable development*. Ecological Economics, 19: 11-17.

Bilaletdin E., Water management planner at the Pirkanmaa Centre for Economic Development, Transport and the Environment, oral interview 29th of February 2012.

Carpenter, S. R., Caraco, N. F., Correll, D.L., Howarth, R. W., Sharpley, A. N., Smith, V.H., 1998: *Nonpoint Pollution of Surface Water with Phosphorus and Nitrogen*. Ecological Applications, vol. 8, no. 3: 559-568.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and 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.

Carter, N. 2007. The Politics of the Environment – Ideas, activism, policy. 2 nd edition. Cambridge University Press, pp. 1-410.

Coca-Cola and the Nature Conservancy 2010: *Product Water Footprint Assessments – practical application in corporate water stewardship*. Atlanta, US.

Dabrowski, J.M., Murray, K., Ashton P.J & Leaner J.J (2009) *Agricultural impacts on water quality and implications for virtual water trading decisions*. Ecological Economics, 68: 1074-1082.

Ecoinvent 2.2 (2011) http://www.ecoinvent.ch/ accessed on 27.2.2012

Ekholm, P., Malve, O. and Kirkkala, T. 1997: *Internal and external loading as regulators of nutrient concentrations in the agriculturally loaded Lake Pyhäjärvi (southwest Finland)*. Hydrobiologia, 345: 3–14.

Ekins, P. 2003: *Identifying critical natural capital: Conclusions about natural capital*. Ecological Economics, 44: 277-292.

European commission, 2012: Ecological status and intercalibration. http://ec.europa.eu/environment/water/water-framework/objectives/status_en.htm accessed on 04.05.2012

European Parliament and of the Council of the European Union, 2000: *establishing a framework for Community action in the field of water policy*. Directive 2000/60/EC.

European water partnership 2012: European water stewardship http://www.ewp.eu/activities/water-stewardship/ accessed on 03.05.2012

FAO Aquastat 2012: Country fact sheet Finland. Generated: 26 Apr 2012

FAOSTAT (2012) http://faostat.fao.org/site/567/default.aspx#ancor accessed on 29.03.2012

Finland Proper Environmental Centre, 2012: Aurajoki-Paimiojoki 1980-2005 [Aura river – Paimio River 1980-2005]. http://www.ymparisto.fi/default.asp?node=20546&lan=fi accessed on 21.03.2012

Finnish meteorological institute (2012): *Meteorological data from Jokioinen weather station for year 2011*.

Gerbens-Leenes, W., Hoekstra, A.Y. and Van der Meer, T.H. (2009) *The water footprint of bioenergy*. Proceedings of the National Academy of Sciences, 106 (25): 10219-10223

Hajer, M. A. 1995: *The politics of environmental discourse : ecological modernization and the policy process*. Oxford University Press, New York. DOI: 10.1093/019829333X.001.0001

HELCOM, 2011: *The Fifth Baltic Sea Pollution Load Compilation (PLC-5)*. Balt. Sea Environ. Proc. No. 128.

Hoekstra, A.Y. 2003: *Virtual water trade between nations: a global mechanism affecting regional water systems*. IGBP Global Change News Letter, No. 54, pp. 2-4.

Hoekstra, A.Y. and Chapagain, A.K. 2007: *Water footprints of nations: water use by people as a function of their consumption pattern*. Water Resources Management, 21: 35-48.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. 2011: *The Water Footprint Assessment Manual: Setting the Global Standard*. Taylor & Francis.

Kangas, A., Laine, A., Niskanen, M., Salo, Y., Vuorinen, M., Jauhiainen, L. & Nikander, H. (2011) *Results of official variety trials 2004-2011*. MTT, Jokioinen.

Laurinen, J. 2012: Oat farming in Finland and information about contract farming in the Raisio Group. Personal communication, Raisio, Finland.

Liu, C., Kroeze, C., Hoekstra, A. Y., Gerbens-Leenes, W. 2012: *Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers*. Ecological Indicators, 18: 42-49.

Liverman, K. Richardson, P. Crutzen, and J. Foley. 2009: *Planetary boundaries:exploring the safe operating space for humanity*. Ecology and Society 14(2): 32.

Maanmittauslaitos (2011), maps accessed from: http://www.maanmittauslaitos.fi/aineistot-palvelut/digitaaliset-tuotteet/ilmaiset-aineistot/hankinta on 30.01.2012

Mekonnen, M. M. and Hoekstra, A. Y. 2011: *The green, blue and grey water footprint of crops and derived crop products*. Hydrol. Earth Syst. Sci., 15, 1577–1600.

Meybeck, M. 1982: *Carbon, Nitrogen, and Phosphorus transport by world rivers*. American Journal of Science, vol 282: 401-450.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., & Olsson, L. (2007). *Categorising tools for sustainability assessment*. Ecological Economics, *60*(3), 498-508. doi:10.1016/j.ecolecon.2006.07.023

Pote, D. H. Daniel, T. C. Sharpley, A. N. Moore, P. A. Edwards, D. R. and Nichols, D. J. 1996: *Relating Extractable Soil Phosphorus to Phosphorus Losses in Runoff*. Soil Sci. Sac. Am. J. 60: 855-859

Postel, S. L., Daily, G. C., & Ehrlich, P. R. (1996). *Human Appropriation of Renewable Fresh Water*. *Science*, *271*(5250), 785-788. doi:10.1126/science.271.5250.785

Raisio Group Annual Report 2011: http://annualreport2011.raisio.com/ Accessed on 27.04.2011

Raworth, K. 2012: *A safe and just operating space for humanity – can we live within the doughnut?*. Oxfam Discussion Paper.

Rep, J. 2011: *From forest to paper, the story of our water footprint*. UPM-Kymmene.

Ridoutt, B. G. Pfister, S. 2010: *A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity*. Global Environmental Change 20: 113–120.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, III, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B.H., Liverman, D., Richardson, K., Crutzen, C. and Foley. J. 2009: *A safe operating space for humanity*. Nature 461, 472-475. doi:10.1038/461472a

Ränkman, E. 2010: *Tehopohjavesiprosessin tarkastelu ja kehittäminen Nokian vesilaitoksella* [Inspection and development of intensive artificial groundwater recharge at the Nokia water purification plant]. Diploma work for Tampere University of Technology.

Saarinen, M. Kurppa, S. Nissinen, A. and Mäkelä J. 2011: *Aterioiden ja asumisen valinnat kulutuksen ympäristövaikutusten ytimessä* [Food and living consumption choices in the core of environmental impact]. ConsEnv final report, Environmental Ministry, Helsinki, Finland.

Salmi, P., & Kipinä-Salokannel, S. (2010). *Satakunnan pintavesien toimenpideohjelma vuoteen 2015 (Action Plan for Satakunta surface waters until 2015)* (pp. 1-152). Finland proper.

Solow, R. 1993: *An almost practical step towards sustainability*. Resources policy, pg. 162-172.

Suttie, J.M. (2000): *Avena sativa L. fact sheet*. FAO, accessed on 29.03.2012

UN 1948: *The Universal Declaration of Human Rights.* Geneva: UN. Available at: http://www.un.org/en/documents/udhr/ last accessed on 11.05.2012

UN water 2012: Water use statistics. http://www.unwater.org/statistics_use.html accessed on 05.05.2012

Valtion ravitsemusneuvottelukunta (National Nutrition Council), 2005: *Suomalaiset ravitsemussuositukset – ravinto ja liikunta tasapaino* (Finnish nutritional recommendations – the nutrition and exercise balance). Helsinki, Finland.

World Health Organization 2012: *Water related diseases – Methaemoglobinemia. Available* at: http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/ accessed on 06.06.2012

Wichelns, D. 2001: *The role of 'virtual water' in efforts to achieve food security and other national goals, with an example from Egypt*. Agricultural Water Management, 49: 131-151.

WWAP (World Water Assessment Programme), 2012: *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris, UNESCO.

Zarate, E. 2010: *WF Grey Water Footprint Working Group Final Report*. Water Footprint Network, Enschede, Netherlands.

Appendix I : An example of C_{max} and C_{nat} calculations

Nitrogen leaching

$$\max(a + b\Delta''_{n}, c)$$

a= constant (kg/ha,a)
b = nitrogen balance factor (1/a)
c = minimum leaching (kg/ha,a)

Phosphorus leaching

Dissolved phosphorous

Phosphorus concentration in leached surface water :

$$C_{P,surface} = \beta(a \times P_{soilp} - b)$$

β = fertilizer application method factor
a = factor for P_{soilp} (µg/l)
b = constant (µg/l)
P_{soilp} = the concentration of easily soluble phosphorus which is available for the plants (mg/l)

Subsurface phosphorus leaching concentration $C_{P,subsurface}$ =

$$\kappa C_{P,surface}$$

κ = constant depending on the soil type and tiling method

Leaching of phosphorus (kg/ha,a) is finally calculated with the formula:

$$m''_{PD} = V''_{surface}\, C_{P,surface} + V''_{subsurface}\, C_{P,subsurface}$$

$V''_{surface}$ = surface flow (kg/ha,a)

$$V''_{P,surface} + V''_{P,surface} = V''_{total}$$
$$V''_{subsurface} = \alpha V''_{total}$$

V''_{total} = total runoff (m^3/ha,a)
α = constant

Particulate phosphorus

$$m''_{PP} = a \times m''_{Er}\, C_{PP}$$

m''_{PP} = leaching of particulate phosphorus (kg/ha,a)
a = availability factor (constant)
m''_{Er} = erosion speed (kg/ha,a)

C_{PP} = total phosphorus content of soil particles (kg/kg)

Sample calculation for phosphorus and nitrogen leaching for one farmer

C_{nat} = < 12 µg/l = 0,000012 kg/m3
Cmax = < 35 µg/l = 0.000035 kg/m3

Farmer information Clay soil, P=14,7
assumption: till farming

Phosphorus leaching

Dissolved phosphorus:

Surface waters:
Cp,surface = 1 ((21µg/l x12.3mg/l)-15µg/l) = 1(0.021x12,3)-0,015 = 0,2433 mg/l

In the actual calculations we use a more specific value for phosphorus readily available in soil for plants use.

Subsurface leaching:
Cp,subsurface = 0.7x0,2433 = 0,17031 mg/l

Leaching of dissolved phosphorus:
Dissolved reactive P (DPR) : m''_{PD} = (((1-0.5)x2700 m^3/ha,v)x 0,2433mg/l)+((0,5x2700m^3/ha) x 0,17031mg/l) = (1350m^3/ha,v x0,2433g/m^3)+((0,5x2700m^3/ha,v) x 0,17031 g/m^3 = (1350m^3/ha,v x 0,0002433kg/m^3)+((0,5x2700m^3/ha,v) x 0,00017031 kg/m^3 = 0,328455+0,2299185 = 0,5583735 kg/ha,v

Erosionphosphorus:

m''_{PP} = 0,16 x (1129 kg/ha,v x 0,0014kg/kg) = 0,252896 kg/ha,v

Total leached phosphorus is dissolved + erosion phosphorus = **0,81 kg/ha,a**

Nitrogen leaching

m''_N = max(1,8 – 0,16×23, 5) = 5 kg/ha,a

Appendix II: Calculation of C_{max} and C_{nat} in the Eura watershed

Yläne river

Natural run-off : P=20%, N=30%
Atmospheric deposition : P=0%, N=0,2%
Stormwater : P=0,1%, N=0,3%
Total: P=7 t/a, N=150 t/a

Pnat = 7*0,201 = 1,407 t/a
Nnat = 150*0,305 = 45,75 t/a

Mean volumetric flow, MQ (1971-2000) = 2,1 m3/s
2,1 meter^3/second = 66225600 m3/year
Pnat = 1,407 t/a / 66225600 m3/a = 2,1245560629122272957889396245561e-8 t/m3/a = 2,125e -5 kg/m3/a

Nnat = 45,75 t/a / 66225600 m3/a = 6,9082046821772849170109444082047e-7 t/m3/a = 6,904e -4 kg/m3/a

Pmax = (target concentration = < 60 µg/l) = 0.000000060 kg/l = 0,00006 kg/m3

Nmax = (target concentration = reduction of 30-40 %)
150 t/a -35% 97,5 t/a
97,5 t/a / 66225600 m3/a = 1,4722403421033558019859389722403e-6t/m3/a = 1,472e -3 kg/m3/a

Lake Pyhäjärvi

Natural run-off : P=19%, N=22%
Atmospheric deposition: P=11%, N=27%
P= 20 µg/l, N=450 µg/l

Pnat = 0,3*20 = 6 µg/l = 0,000006 kg/m3
Nnat = 0,49*450 = 220,5 µg/l = 0,0002205 kg/m3

Pmax = (target concentration = < 18 µg/l) = 0.000000018 kg/l = 0,000018 kg/m3

Nmax = (target concentration = same as current) = 0,000450 kg/m3
450 µg/l

Eura river

Natural run-off : P=18%, N=20%
Atmospheric deposition : P=7%, N=17%

Stormwater : P=0,1%, N=0,4%
Total: P=8 t/a, N=339 t/a

Pnat = 8*0,251 = 2,008 t/a
Nnat = 339*0,374 = 126,786 t/a

Mean volumetric flow, MQ (SYKE, 1971-2000) = 8,7 m3/s
8,7 meter^3/second = 274363200 m3/year

Pnat = 2,008 t/a / 274363200 m3/a = 7,3187657819999183563976509969267e-9 t/m3/a = 7,319e -6 kg/m3/a = 0,000007319

Nnat = 126,786 t/a / 274363200 m3/a = 4,6211007890270998442939869486 87e-7 t/m3/a = 4,621e -4 kg/m3/a = 0,0004621

Pmax = (target concentration = < 60 µg/l) = 0.000000060 kg/l = 0,00006 kg/m3

Nmax = (target concentration = 30-40% reduction) = 0,0008031 kg/m3
339 t/a (current) → -35% → 220,35 t/a
220,35 t/a / 274363200 m3/a = 8,0313249007155478577301912209801e-7 t/m3/a = 8,031e -4 kg/m3/a