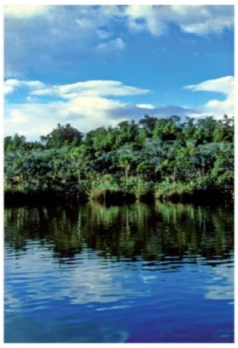

Assessment of the Water Footprint of Fresh Kiwifruit: Methods and Scoping

Final Report

Contract: MAF POL 0910-11522

Landcare Research
Manaaki Whenua

Water footprinting the Kiwifruit supply chain

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Contents

Summary vii

1 Introduction 11

2 Background 11

2.1 Report structure 12

3 Goal and objectives 13

4 Methods 14

4.1 Terminology 14

4.2 Overview of WFN and LCA methods 15

4.3 Scoping 16

5 Orchard production 23

5.1 The orchard survey 23

5.2 Rainfall 23

5.3 Irrigation 24

5.4 Yields 26

5.5 Water use in winter 27

5.6 Electricity 28

5.7 Agrichemical and foliar fertiliser spray applications 29

6 Packhouse and coolstore 29

6.1 The packhouse and coolstore survey 29

6.2 Transport of kiwifruit to the packhouse and coolstore 30

6.3 Packhouse operations 31

6.4 Direct water use, fuel and electricity 39

6.5 Coolstore operations 41

7 Post packhouse/coolstore life cycle stages 44
7.1 Port operations 44
7.2 Shipping 44
7.3 Repacking in Europe 44
7.4 Transport to the retailer 45
7.5 Retailer 45
7.6 Transport from retailer to household 46
7.7 Household consumption 46
8 Results – Orchard, Packhouse and Coolstore 47
8.1 Orchard life cycle stage results 47
8.2 Orchard hydrological perspective 48
8.3 Orchard WFN water footprint 61
8.4 Summary of orchard results 69
8.5 Transport of kiwifruit to the packhouse 70
8.6 Packhouse/coolstore operations 70
9 Results - Post-packhouse/coolstore results 74
9.1 Departure port operations 74
9.2 Shipping New Zealand and the UK 75
9.3 Repacking in Europe 75
9.4 UK Transport 75
9.5 UK retailer 77
9.6 UK household consumption 78
10 Implications and findings 79
10.1 Orchard findings and implications 79
10.2 Transport in New Zealand life cycle stages 84
10.3 Packhouse/coolstore operations 84

10.4 LCA packhouse/coolstore freshwater impacts 84

10.5 Post-packhouse/coolstore life cycle stages 85

10.6 Cumulative environmental impacts 87

10.7 The importance of different life cycle stages 87

10.8 WFN vs. LCA water footprinting 91

11 Recommendations 92

12 Acknowledgements 94

13 References 94

Appendix 1 Sample orchard inventory report 98

Appendix 2 Sample orchard end of season report 99

Appendix 3 Survey form for packhouse/coolstore operations 100

Appendix 4 Estimation of water footprints of input materials for packhouses and coolstores 109

Appendix 5 Estimation of grey water footprints of input materials for packhouses and coolstores 113

Appendix 6 International Peer Review Comments 117

Summary

Project Code

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Landcare Research/ Ministry of Agriculture and Food (MAF) and Zespri International Ltd

Programme Leader

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Programme Title

- Sustainable Business

Goal

- The goal of the study is to investigate the freshwater consumption (water footprint) of the green kiwifruit supply chain.

There are four specific justifications for this research:

- Opportunities to continue to secure premium pricing through eco-verified linkages to the environmental attributes of products
- Potential emerging compliance requirements for market access to large retail chains
- Identification of hotspots of high opportunity costs associated with 'blue' water, and the eco-efficient advantages that accrue from reducing its size in the total water footprint
- Combining expertise within the kiwifruit industry with research support will enable the industry and its growers, packhouse operators, and customers to gain a better understanding of water use and reduction opportunities across their entire supply chain. It will also contribute to a standard approach for continued water resource measurement and management within the industry.

Context of the project

The research has been completed in response to the increased focus on business freshwater consumption and the impact of products on the environment. In 2008 the kiwifruit supply chain was documented and studied during a carbon footprinting exercise. The carbon footprinting study identified areas of potential carbon reductions across the whole supply chain.

The use of product-orientated carbon footprinting measures within the kiwifruit industry serves as a good example of how focussing on a single environmental issue can produce significant improvement in environmental performance and minimise the business risks associated with horticultural exports.

The development of a new International Standards Organisation (ISO) standard on water footprinting and the formation of Water Footprint Network (WFN) in 2008 have focused the attention of the international business community on the environmental impact of the water footprint of products. Numerous case studies to establish water footprints are being worked on internationally and it is possible that eventually a mature water footprinting methodology could be used in labelling schemes for products. Both MAF and Zespri are keen to investigate the issues raised by the development of new water footprinting methodologies through practical application in the green kiwifruit supply chain.

Approach

The approach taken in this research was agreed by the project steering group and guided by the project proposal. The water footprint of green kiwifruit was investigated using two water footprinting methods:

- First, the method advocated by the WFN for establishing a water footprint was applied to the green kiwifruit supply chain.
- Second, the WFN results were used to assess the environmental impact of freshwater consumption using Life Cycle Assessment (LCA) characterisation factors. Two different characterisation factors were examined. Initially, the characterisation factor from Milà i Canals et al. (2009) was applied to provide the Freshwater Environmental Impact (FEI indicator). Results from the WFN method were then examined using a regional Water Stress Index (WSI) provided by the work of Pfister et al. (2009) to provide a greater insight into the potential regional environmental impact.

A third method is also included in this report based on hydrological water balance methods. The hydrological approach provides an alternative perspective on the work of the project and the possible reduction options that might arise from water footprinting.

Primary data collection is based on an orchard and packhouse survey and modelling of water movements through plant growth, soil, and groundwater using the Soil-Plant-Atmosphere-Model (SPASMO). Investigation of the post packhouse/coolstore life cycle stages was based on secondary literature sources.

Summary of outcomes

- The WFN footprint was established for orchard operations in 10 green kiwifruit cultivation regions including the major cultivation region of Te Puke.
- The WFN investigation of the water footprint revealed difficulties in the interpretation of the WFN guidance manual. Differences in interpretation led to the development of an alternative view of the WFN water footprint being developed for the orchard life cycle stage. The alternative perspective is based on a hydrological water balance approach; while the WFN water footprint is based on consumptive product footprint

approaches. The main differences in the approaches are the treatment of rainfall, run-off, and drainage in establishing the water footprint.

- The hydrological perspective and WFN water footprint provided two different figures for freshwater abstraction and consumption at the orchard. For example, in the hydrological perspective the national average WFN water footprint (excluding grey water or water needed to restore water to a pristine condition) is –560 l/TE (litres per tray equivalent) and in the WFN water footprint approach 1501 l/TE. The negative value in the hydrological perspective describes a net groundwater recharge from green kiwifruit cultivation in the orchard life cycle stage.
- In the WFN water footprint the majority of water consumed at the orchard life stage is derived from water available in soil moisture (green water), while recognising that in an irrigated situation some of this soil moisture has been provided by pumping and applying blue water. Eighty-five percent of the weighted national average WFN total water footprint for the orchard is green water, 5% blue water, and 10% grey water.
- The weighted national average WFN total water footprint for a kg of Class I of green kiwifruit at the orchard is 417 l kg fruit produced. Assuming each kiwifruit weighs 100 g, the WFN total footprint at the orchard based on the weighted national average per kiwifruit is 42 l.
- In the hydrological water perspective the most important part of the water balance is the impact of grey water.
- LCA characterisation of the results from the WFN blue water footprint at the orchard life cycle stage led to further insights into the environmental impacts of freshwater consumption.
- The calculation of an FEI indicator is based on the percentage of actual water resources being used called the Water Use per Resource (WUPR). A high WUPR indicates a serious water stress as most freshwater is used or resources are depleted faster than they can be renewed. For example, national figures for WUPR described in Milà i Canals et al. (2009) range between 0 % for the Democratic Republic of Congo and 258% for Qatar. Water stress in the Democratic Republic of Congo is low and high in Qatar. Characterisation of the WFN blue water footprint using WUPR figures in the method described by Milà i Canals et al. (2009) to provide a FEI indicator made little difference to the pattern of results produced by the WFN orchard water footprint results, because only a single national characterisation factor is available for New Zealand.
- The calculation of the WSI is based on the WaterGAP 2 global hydrological and global water use models with modifications to account for monthly and annual variability of precipitation and corrections to account for watersheds with strongly regulated flows. The application of the regional WSI discussed in Pfister et al. (2009) to the orchard results highlighted the higher environmental impact in regions with relatively low green kiwifruit production, for example, in the Auckland region where the impact of freshwater consumption is high relative to the contribution to the national production.
- The WFN water footprint for the packhouse and coolstore life cycle stage is 105.5 l/TE. The packing material used for a tray equivalent of green kiwifruit has a total WFN water footprint of 7.99 l/TE. Due to a lack of readily available data the water footprint for packaging materials is derived from electricity consumption in the production of packing materials only and therefore may be understated. Activities at the coolstore contribute 79.2 l/TE to the WFN water footprint at this life cycle stage.

- The WFN blue water results for packhouse/coolstore operations once characterised produce an FEI of 0.084. Using WSI 0.0107 leads to an impact of 0.003 for freshwater consumption in packhouse/coolstore operations.
- Beyond the packhouse/coolstore life cycle (e.g., in repacking, distribution, retailing or household consumption) a lack of readily available data limited the ability of the research to establish a WFN water footprint and LCA based water footprint. In the majority of life cycle stages data for the water footprint are based only on electricity use. The use of electricity and data quality problems result in a high level of uncertainty in the water footprint results obtained for latter parts of the supply chain.
- The research into the latter stages of the supply chain was not able to predict with certainty the hotpots of freshwater consumption in the supply chain. Despite it being possible to express a high degree of confidence in the water footprint at the orchard life cycle stage, the numerous gaps and omissions in the research mean a total water footprint figure that covers all life stages for green kiwifruit was not produced. Given the limitations of the research it is difficult to gauge the accuracy and validity of any figure produced, and it is possible the large number of assumptions needed to complete research would render a single total figure virtually meaningless.
- For the most part, illustrative examples of issues for further investigation are highlighted in the downstream life cycle stages. At first glance, the household consumption footprint would appear small because kiwifruit is not normally cooked or washed but eaten raw. Results in this study however, suggest that, depending on the geographical location of where fruit is consumed, environmental impacts at the household consumptions stage may be significant.

Summary of main recommendations

The research has highlighted a number of potentially important areas for future research. In summary, further work is needed in the following areas:

- Primarily, there is a need for the collection of appropriate specific data to increase the scope and reliability of inventory data for determining blue and green water consumption across the supply chain
- Data available from water footprinting studies are increasing rapidly but further New Zealand case studies would identify what standardised data are needed; for example, an agreed blue water footprint for the New Zealand electricity mix and for packaging materials, e.g., cardboard
- Another important future issue will be how to support the ongoing collection of data for water footprint measurement at the orchard in a efficient manner, for example, to investigate the appropriate mix of survey, measurements, and modelling needed to support water footprinting in the horticulture sector
- Investigation of the water footprint in post-packhouse/coolstore life cycle stages including the household consumption stage to reduce uncertainty of the major hotspots within the supply chain.

Further detailed recommendations are outlined in Section 11.

1 Introduction

This methods and scoping report is the second output of the Assessment of the Water Footprint of Fresh Kiwifruit project. The project is undertaken on behalf of Zespri International Limited and The Ministry of Agriculture and Forestry. This work is led by Landcare Research in collaboration with the Plant and Food Research Institute of New Zealand and with support from AgriLINK New Zealand. The research was carried out between November 2009 and June 2010.

This project aims to begin the process of exploring and investigating current methodologies for the measurement of the water footprint of the Kiwifruit supply chain. Our intention with this methods and scoping report is to highlight important information for the kiwifruit industry about the Water Footprinting Network (WFN) initiatives and Life Cycle Assessment (LCA) in water footprinting, and to summarise the advantages and disadvantages of these different methods. The primary means used to investigate these water footprinting methods is by their application within the industry.

This document also offers important insights into the development and maturity of water footprinting techniques and the data and technical difficulties associated with completing a water footprinting exercise within the green kiwifruit supply chain. Due to the exploratory nature of this project, this method and scoping document is not intended as a comprehensive examination of all aspects of water footprinting but rather is focussed on the application of the WFN method and the assessment of environmental impact of water use using LCA.

Both the WFN and LCA methods discussed in the document are outlined in 'Assessment of the Water Footprint of Fresh Kiwifruit: Update and Review' (Hume 2010) and the MAF water footprinting literature review report 'Water footprinting. Drivers, Methodologies, Challenges' (Finkbeiner 2009).

2 Background

Kiwifruit is New Zealand's largest horticultural export, and Zespri International Limited (ZESPRI™) is the largest kiwifruit exporter in the world. Kiwifruit and the associated name ZESPRI™ is an iconic New Zealand brand with a high degree of global consumer recognition. Emerging supply chain requirements for continued market access in overseas export markets necessitate the kiwifruit industry investigating and achieving water efficiency across the whole supply chain.

In 2008 the kiwifruit supply chain was documented and studied during a carbon footprinting exercise. Two approaches to GHG footprinting were used to inform the discussion: product-focused LCA (based on ISO 14040 and 14044) and the UK's draft Publicly Available Specification (PAS) for greenhouse gas (GHG) emission measurement of goods and services (Mithraratne et al. 2010). The use of product-orientated carbon footprinting measures within the kiwifruit sector serves as a good example of how focussing on a single environmental issue might produce significant improvement in environmental performance and help reduce the business risks associated with horticultural exports.

The Bay of Plenty is a major growing region for New Zealand kiwifruit. In recent years a number of studies have been completed on the subject of the sustainable management of water resources. For example, in 2007 Aqualinc Research completed a study of water use and availability in the western Bay of Plenty, including Tauranga. The Aqualinc study identified important drivers for increases in water demand including:

- Population growth – population in the area is projected to grow from approximately 142 000 in 2005 to approximately 290 000 in 2055.
- Agriculture – a possible large increase in irrigation for most types of crop grown within the Bay of Plenty. The report suggests that annual water demands for horticultural crop production are expected to double from approximately 7 million cubic metres to approximately 14 million cubic metres in 2055.

In a 2009 Institute of Geological and Nuclear Sciences (GNS Science) technical review of the Aqualinc study, groundwater availability estimates in the earlier study were compared with the findings of two recent GNS reports covering the region. The review supported the earlier overall conclusion by Aqualinc that surface waters in the area may not support future water demand in the region and that groundwater resources would become increasingly important. Groundwater allocated for use in the region is estimated at approximately 15 100 L/s (White et al. 2009a, 2009b).

The GNS findings also pointed out Environmental Bay of Plenty's allocation policies for water resources will be key for conserving and managing groundwater resources within acceptable limits (White et al. 2009b). In response to the rising awareness of water scarcity issues Environment Bay of Plenty has developed a Water Sustainability Strategy (2008).

The direct or indirect result of either intentional or unintentional mismanagement of water can be seen in reputation impacts, increased costs, and changes to regulation. Businesses will be required not only to ensure their facilities are being optimally run in terms of water usage but also to ensure their activities are transparent to the wider community with open channels of communication (SABMiller 2009). More information on the business risks associated with freshwater consumption is provided Hume 2010.

Set out against the background of this recent research in the Bay of Plenty and the growing awareness of the need to manage the environmental impact of water use by-products, Zespri™ is keen to assess the ability of different water footprinting methods to describe the water footprint of fresh kiwifruit and explore opportunities for the reduction of freshwater use.

2.1 Report structure

This report investigates freshwater consumption use at different life cycle stages within the green kiwifruit supply chain. Issues relating to data, methodology, and recommendations for specific methods and/or further research are included in the description of each life cycle stage.

The remainder of this report discusses:

- The goals and objectives of the study (Section 3)
- The water footprinting methods and terminology used in this research (Sections 4)
- Results of the orchard survey (Section 5)
- Results of the packhouse/coolstore survey (Section 6)
- Data for post packhouse/coolstore life cycle stages (Section 7)
- Water footprint results for the orchard life stage and the packhouse/coolstore life cycle stage (Section 8)
- Water footprint results post packhouse/coolstore life cycle stages (Section 9)
- The main findings and recommendations for further work (Section 10)
- Recommendations for further research (Section 11)

3 Goal and objectives

Methodologies focusing on freshwater consumption at the product level have gained increasing prominence internationally. The goal of this project is to understand the challenges in providing an accurate water footprint for fresh New Zealand Kiwifruit and (where feasible, based on the available data) identify opportunities for the reduction of water use within the supply of kiwifruit to consumers. In other words, the objective is to have a clear understanding of the practical implications of the implementation of a water footprint methodology.

There are four specific justifications for this research:

- Opportunities to continue to secure premium pricing through eco-verified linkages to the environmental attributes of products
- Potential emerging compliance requirements for market access to large retail chains
- Identification of hotspots of high opportunity costs associated with 'blue' water, and the eco-efficient advantages that accrue from reducing its size in the total water footprint
- Combining expertise within the kiwifruit industry with research support will enable the industry and its growers, packhouse operators, and customers to gain a better understanding of water use and reduction opportunities across their entire supply chain. It will also contribute to a standard approach for continued water resource measurement and management within the industry.

The wider context for the research is to ensure the New Zealand kiwifruit sector can operate within export markets using internationally recognised, transparent, and validated water footprinting techniques in the future. An understanding of freshwater consumption in the supply chain of kiwifruit will lay the foundations for reduction options across the industry and increase knowledge for discussions with international stakeholders. For example, in discussions related to the forthcoming ISO Water Footprinting Standard or with major retail customers, e.g., Marks and Spencer in the UK.

4 Methods

4.1 Terminology

In order to provide consistent wording throughout this report, the terminology proposed by the UNEP-SETAC Life Cycle Initiative (Bayart et al. (2010) has been adopted. This is also the terminology used by Finkbeinder (2009). Accordingly, the term freshwater use is divided into the categories *in-stream freshwater use* and *off-stream freshwater use*. While in-stream freshwater use describes an in situ use of freshwater (e.g., for hydroelectric power or ship traffic), off-stream freshwater use comprises any use of freshwater that requires a prior removal of freshwater from the water body. Additionally, freshwater use can be divided into *freshwater degradative use* and *freshwater consumptive use*. Freshwater degradative use is characterised by withdrawal and discharge of freshwater into the same water body after quality alteration. In contrast, freshwater consumptive use occurs when used freshwater is not released into the same water body from which it was withdrawn due to product integration, evaporation, or discharge into different water bodies. Based on these two sub-divisions, the following four types of freshwater use are defined:

- In-stream freshwater degradative use, e.g., temperature increase of water retained in dams or reservoirs;
- In-stream freshwater consumptive use, e.g., additional evaporation of water retained in dams or reservoirs;
- Off-stream freshwater degradative use, e.g., increase of biochemical oxygen demand between water catchment and waste water treatment plant effluent; and
- Off-stream freshwater consumptive use, e.g., the fraction of irrigation water that is evaporated.

In addition to the terminology listed by Finkbeiner (2009), the WFN method defines two different types of freshwater consumptive water use (green and blue) and one degradative water use (grey), which are important in this study.

Green water refers to the consumption of rainwater stored in the soil as soil moisture and available for evaporation (evapotranspiration) through crops and vegetation (Hoekstra et al. 2009; Milà i Canals et al. 2009). Therefore the green water content of a product is the volume of rainwater that evaporated during the production process. This is normally highly relevant for agricultural products, where it refers to the total rainwater evaporation from the field during crop growth (including both transpiration of plants and other forms of evaporation (Hoekstra 2008).

Blue water refers to surface- or groundwater. It is the volume of water in ground- (aquifer) and surface water (lakes, rivers, reservoirs) bodies available for abstraction. Consumption of blue water refers to loss of water from the available ground- or surface-water body in a catchment area, which happens when water evaporates and returns to another catchment area or the sea or is incorporated in a product (Hoekstra et al. 2009). In the case of crop production, the blue water content of the crop is defined as the sum of the evaporation of irrigation water and the evaporation of water from irrigation canals and man-made reservoirs. In industrial production or domestic water supply, the blue water content of the product or service is equal to the part of the water withdrawn from ground- or surface water that evaporates and thus does not return to the system where it came from (Hoekstra et al. 2009).

The distinction between blue water and green water is important, as green water is only available for use by plants at the precise location where it occurs, whereas blue water is available generally for use in a wide range of human-managed systems, including but not limited to use by plants (Milà i Canals et al. 2009).

Grey water is related to the quality of water for use further downstream (or down gradient in the aquifer) as a result of polluted return flows. A common misunderstanding is that grey water is the amount of polluted water produced from activities within the system. In fact, grey water is defined as the volume of additional freshwater required to assimilate or dilute the load of pollutants based on existing ambient water quality standards rather than the amount of polluted water generated (Hoekstra et al. 2009).

In this study the WFN water footprint is "the volume of freshwater used to produce the product, measured at the place where the product was actually produced (production-site definition)". The term "virtual water", sometimes used in the literature, refers to the fact that most of the water used to produce a product is not contained in the product.

4.2 Overview of WFN and LCA methods

At the time of writing, discussions within the international community on the drafting of an international standard for water footprinting are at an early stage of development. Since there is no agreed international standard to guide the water footprinting exercise for kiwifruit, two methods have been used in this project. The methodology advanced by the WFN has been chosen for closer examination because it has quickly become the most publically recognised method for describing the water footprint of a nation or product. The method is currently being tested by a list of 60 companies within the WFN and several primary sector products have been examined in studies using the WFN methodology including apples, beef, and cheese (Hume 2010). At the time the research was completed the most comprehensive guide to the WFN water footprinting method was given in 'Water Footprint Manual, State of the Art 2009' (Hoekstra et al. 2009). The 2009 version of the Water Footprint Manual has been used as the basis of the WFN water footprint determined during this research.

There is a general belief that meaningful, valid, and robust approaches to assessing a product's environmental impact should be based on life cycle thinking, i.e. the complete product system and supply chain of a product, rather than single production, use, or end-of-life stages. The life cycle perspective helps decision makers in business and government take into account all the resources consumed and environmental impacts associated with the supply, use, and end-of-life of goods and services (products). All other things being equal, this provides a fair basis for product comparisons, to effectively identify options for improvements, and to monitor progress in environmental performance both in production and consumption.

Life cycle assessment (LCA) is a common tool used to establish the environmental attributes of products using life cycle thinking or a cradle-to-grave perspective. It is guided by two ISO standards: ISO14040, which provides an overview of LCA; and ISO 14044, which gives more detailed guidance about undertaking an LCA study. In recent years LCA based methods and environmental impact indicators have been developed for inclusion of the environmental impacts of freshwater use. The LCA method chosen for further investigation based on the agreement of the project steering group is the method developed in Milà i Canals et al. (2009). This method is among the most complete LCA methods for water footprinting developed to date, but does have limitations, as discussed in Finkbeiner (2009) and Hume (2010).

The reasons for choosing the method outlined by Milà i Canals et al. (2009) for closer examination mainly relate to the fact it has recently been used to illustrate the consumptive use of freshwater for crop cultivation, including broccoli and tomatoes. Few LCA based methods focus on all types of freshwater consumption and use. The WFN water footprint accounts for the volume of off-stream freshwater degradative or the quantity of water polluted (grey water). LCA typically accounts for the impact of water pollution, although this is usually done through a series of environmental indicators including aquatic ecotoxicity, acidification, human toxocity, and eutrophication rather than a specific or single freshwater consumption indicator. Furthermore, the consumption of green water is only accounted for by a small number of water footprinting methods, including the WFN water footprint and in Milà i Canals et al. (2009). It is therefore important that any exploratory research into freshwater consumption for the green kiwifruit supply chain should consider the methods outlined by both the WFN and Canals.

As highlighted in section 4.1, the WFN water footprint provides a volumetric measure of water consumption. The LCA water footprint provides an assessment of the environmental impact of freshwater consumption by using characterisation factors (a factor that relates the volumetric blue water used to its potential environmental impact to show the relative impact of consumption). In the chosen approach for this study the volumetric measurements from the WFN method are complementary with an LCA water footprint, and used as the basis of calculating an LCA indicator of environmental impact. Late in the project, regional Water Stress Indices (WSI) from the work by Pfister et al. (2009) were also used to help examine differences in the water footprint of different kiwifruit growing regions. However, it must be stressed that the whole methodoloogy outlined by Pfister et al. (2009) was not followed during this research.

The WSI described by Pfister et al. (2009) is based on the WaterGAP 2 global hydrological and global water use models with modifications to account for monthly and annual variability of precipitation and corrections to account for watersheds with strongly regulated flows. The index follows a logistic function ranging from 0.01 to 1. The WSI has a spatial resolution of 0.5 degrees, which is more relevant to describing water stress at a local watershed level than indicators that are based on national or per capita statistics. The use of the regional WSI provided further insights into the environmental impact of freshwater consumption.

4.3 Scoping

In order to provide results from the research that were easily understood by the kiwifruit sector the project initially looked to the earlier GHG footprinting exercise for guidance. The GHG footprinting research was completed for the industry in 2008 (Mithraratne et al. 2010). However, it is essential when tackling a water footprint to think about the specific issues that will arise that relate to the freshwater consumption. For this reason, in this study, assumptions and data used in GHG footprinting report have sometimes been used when appropriate or have been revised or rejected during completion of the study.

LCA functional unit

An LCA is concerned with establishing the environmental impact of a product across its entire life cycle. The ISO 14040 series of LCA standards specify that a functional unit should be defined that describes the unit of analysis for any study.

For the kiwifruit industry a functional unit could be either a number of portions of fruit or a specified weight of fruit. For this study, the functional unit is taken as 'a single-layer-tray equivalent quantity of green kiwifruit delivered to the retailer'.

A weighted-average single-layer tray for all green kiwifruit categories weighs 3.615, of which total fruit weight is 3.3 kg and the remainder packaging). Each tray may contain from 18 to 36 kiwifruit depending on the size of the kiwifruit (Mithraratne et al. 2010); for this study, it is assumed a tray contains 33 kiwifruit, each weighing approximately 100 g.

Zespri Green (also known as 'Hayward') and 'Hort16A' or Zespri Gold are the two main non-organic kiwifruit varieties grown in New Zealand. This study focuses only on green kiwifruit. This study also excludes consideration of the water footprint of non-export grade fruit except when details are needed for allocation between different grades of fruit.

LCA system boundary

The study assesses the water footprint of the "production and delivery of export quality green kiwifruit to a consumer in UK". The description of the systems boundary is consistent with the approach adopted by the previous kiwifruit carbon footprinting exercise and was chosen by the project steering committee to ensure the research in this project built on data sources already collected in previous work.

In order to carry out a water footprint, more detail has been added to the description, e.g., it is important to confirm if export quality kiwifruit is an unambiguous description. The system boundaries in the LCA extend from extraction of raw materials from the ground through to sewage treatment after consumption of kiwifruit. However, as ISO14040 notes (section 5.2.3), 'resources need not be expended on the quantification of such inputs and outputs that will not significantly change the overall conclusions of the study'. Therefore, definition of system boundaries is an iterative process and is guided by the process of learning about the product system as the study proceeds. This is reflected in the discussions below about each stage of the kiwifruit life cycle (Mithraratne et al. 2010).

The following inputs to the supply chain are omitted from the analysis due to the lack of readily accessible data:

- Orchard: beehive pollinators – transport and materials; contractors' and orchard capital equipment
- Packhouse: bins and pallets, packing materials, e.g., shrink wrap, adhesive used for trays, transport of fruit waste to landfill; construction and maintenance of packhouse building and equipment
- Transport: the efficiency gains due to loading, packaging, etc., in transport activities are disregarded as transport is modelled using the weight and distance

- New Zealand port: energy use for handling
- Repackaging facility, Europe: energy use for handling and repackaging, packaging material (although spifes[1] are included).

WFN unit of analysis and process boundary

The WFN method does not explicitly define the need for a functional unit or systems boundary but does state 'the water footprint of intermediate or final product is the aggregate of water footprints of the various process steps relevant in the production of the product' (Hoekstra et al. 2009).

There are no guidelines on this topic apart from the general recommendation of including the water footprint of all processes within a production system that significantly contribute to the overall water footprint. In practice only a few process steps substantially contribute to the total water footprint of the final product. One can expect that agricultural production will make a major contribution to the overall impact of the product containing an agricultural product, while industrial supply chain components will be apparent from impacts associated with grey water (Hoekstra et al. 2009).

A common practice is to exclude labour from the footprinting of a product as it can generate double counting. In general, the water footprints of transport and energy into production systems are excluded from a product water footprint (except if biofuels are used for transportation or if energy originates from biomass combustion and hydropower).

The WFN method provides a volumetric measure of freshwater consumption in the supply chain that is useful in water resources management (Milà i Canals et al. 2009). If the water footprint is the sum of the water use in different processes in the production then it is reasonable to assume that water from different processes will be converted into a single unit of analysis to make the results easier to understand. In this study the WFN water footprint is expressed in terms of litres per kiwifruit tray equivalent (TE) supplied to UK retailers to facilitate a broad comparison between WFN and LCA results whenever possible.

When viewed from a systems analysis perspective the water footprint definition above also implicitly defines an equivalent to a LCA system boundary for the product. In this case we have assumed the WFN process boundary is the same as the system boundary defined for the LCA research completed. In other words all processes that are considered for the LCA approach should also be considered for inclusion in the WFN water footprint unless the WFN guidance recommended otherwise. In Figure 1 the product life cycle for green kiwifruit examined in this study is illustrated for reference.

[1] Spifes are half spoon, half knife plastic utensils about 10 cm (4 inches) long. The knife end is used to slice a kiwifruit in half; the spoon end is then used to scoop out the fruit.

Time boundaries

Typically, it is important in a life cycle footprinting exercise to collect data for a meaningful period of time that will help communicate the results to a wider audience. In this study the water footprint of the 2009/2010 harvest season has been examined. The April to April season is a normal time period considered for the study of an annual yield of green kiwifruit. All freshwater consumption included in this study therefore occurs between April 2009 and April 2010.

With respect to time boundaries, the yield of kiwifruit can vary widely from year to year; data on average yields per hectare for the four years from 2004/05 to 2007/08 indicate that the yield increased by 15% above the lowest average annual yield for green kiwifruit in at least one of those years (J. Chamberlain, pers. comm., 17 June 2008). Even if exactly the same production practices occur each year, yields may vary due to weather conditions.

The ISO 14040 series of standards do not provide specific guidance on accounting for yield variability due to weather conditions. This study investigates the water footprint of kiwifruit on average for 30 years. The timeframe was defined by the availability of climate and soil data necessary to calculate the water footprint at the orchard life cycle stage. Therefore the water footprint calculated for the orchard takes into account rainfall for over 30 years to eliminate the possibility of results centring on a particularly wet or dry year. Climate, soil and kiwifruit plant growth modelling was completed using the Soil-Plant-Atmosphere-Model (SPASMO).

Freshwater data from SPASMO were verified against orchard rain gauge data, water meter data, and soil moisture information collected during an orchard survey. Yield data over the 30 year period were also modelled and verified against Zespri yield data between 2007 and 2010 and the information from the orchard survey.

Several other pieces of data from the orchard survey were also used to check predictions in the SPASMO model. For example, data used from the orchard survey included electricity use for irrigation and pesticide and fertiliser application rates that were later used to establish orchard leachate levels.

During the modelling of the WFN water footprint the blue water footprint for the different regions was examined using four orchard management scenarios modelled by SPASMO. The four management scenarios were rainfed, over-irrigation, efficient irrigation, and frost protection. Rainfed orchards are those that use only rainwater and require no irrigation. Efficient irrigation applies 10mm of irrigation water to the soil once to the plant available water[2] drops below 50% between the surface and a depth of 2 m. Efficient irrigation follows the ‘little more often’ approach. In an over-irrigation management scenario 20 mm of irrigation water is applied every time the plant available water stored in 0 m and 2 m depth is lower than 75%.

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[2] The plant available water is the water available in a soil between the soil matric potential of -60 hPa (= the so called ‘field capacity’) and -15,000 hPa (= the so called ‘permanent wilting point’).

These different scenarios cover the typical water management situations of kiwifruit orchards, and are used to facilitate the discussion of reduction opportunities in Deurer et al. (2010).

For all other parts of the supply chain, including packhouse, coolstore, and repacking UK, data were used from the 2009/10 harvest. However, it is important to recognise yields often vary from year to year.

A point highlighted in the GHG footprint research is that kiwifruit harvested towards the beginning or end of the season may typically be stored for shorter or longer periods of time, and hence have different footprints as a result of the variable time spent in a coolstore. These kiwifruit could potentially be distinguished in the marketplace by the time at which they appear in retail outlets (Mithraratne et al. 2010).

For this awareness-raising study, it is appropriate to use an average storage time to calculate the water footprint. However, further consideration should be given to whether it is appropriate to distinguish between kiwifruit that are harvested at different times in future studies or to evaluate the range of water footprints arising from this variable.

Losses from the kiwifruit supply chain

In the current study the average fruit reject rate at the packhouse is 15% of the total received from the orchard. Four percent of the reject kiwifruit are recovered and sent to the regional markets. The remainder (10%) is either sold to dairy farms as stockfeed or sent for processing (0.6%) (See Table 7 in section 6.3 for more details).

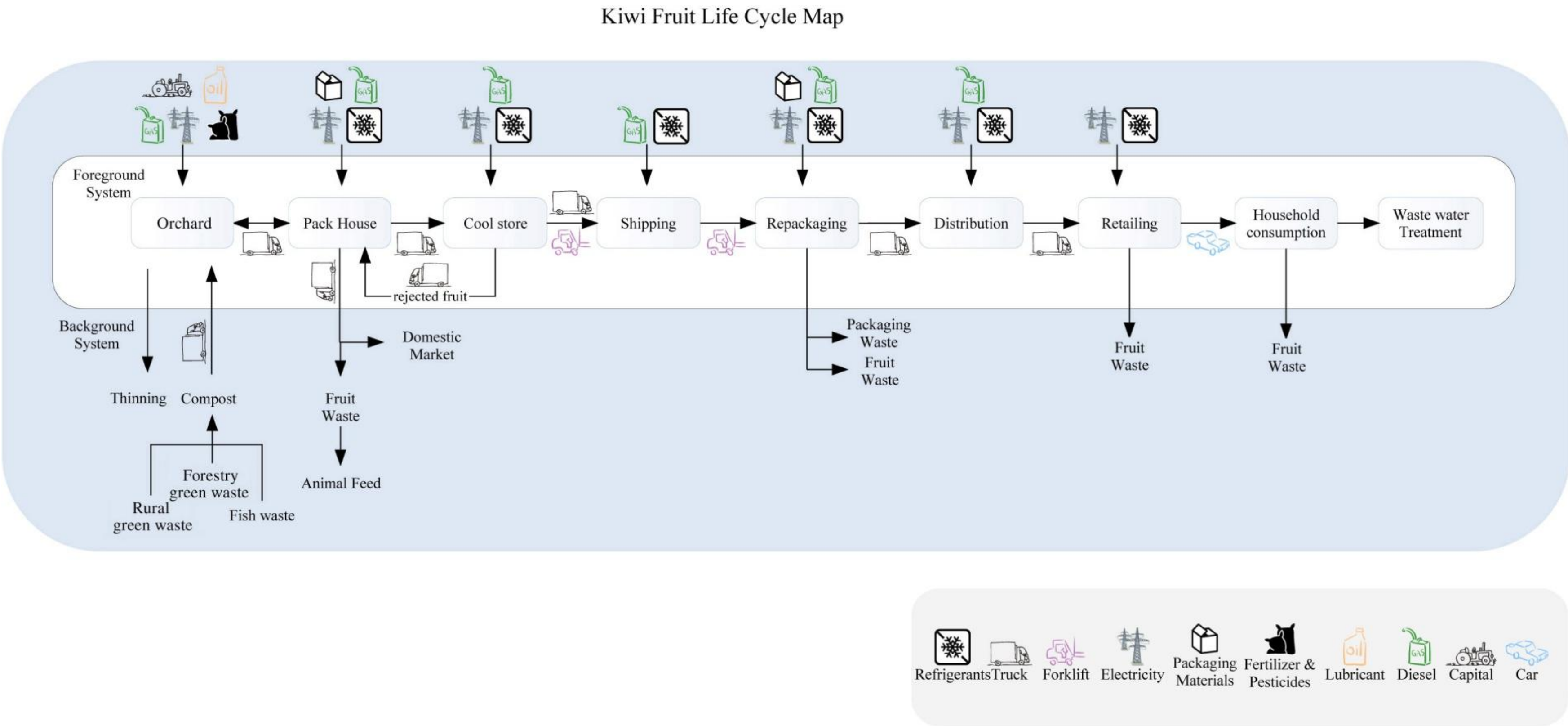


Figure 1Generic green kiwifruit life cycle. Source: Mithraratne et al. (2010)

In Mithraratne et al. (2010) the average fruit reject rate at the packhouse was 17% of the total received from the orchard in 2007/08 harvest season. Seven percent of reject fruit were recovered and sent to the regional markets. Ninety-five percent of the fruit waste was sold to local dairy farms as feedstock, and the balance was sent to landfill. The wastage between the repackaging facility at Zeebrugge and the customer (including skins of consumed fruit) was assumed to be 10% (actual data were not available) (Mithraratne et al. 2010).

It is usually necessary to account for losses of food products in the supply chain when LCA is applied to products. However, no attempt was made to link the different life cycle stages in this study because it was not possible to establish reliable figures for the water footprint at all life cycle stages. Losses of kiwifruit in the supply chain have been excluded for this reason, although the importance of fruit losses in the supply chain is discussed generally in section 10.5.

Allocation of upstream freshwater consumption between different grades of fruit

Two types of green kiwifruit are produced, either Class I or Class II. All export grade kiwifruit are Class I, and Class II fruit is sold into the New Zealand domestic market. In addition to green kiwifruit, export-grade gold kiwifruit are also produced by many orchards.

The approach adopted in the study is the same as that in Mithraratne et al. (2010). Therefore system expansion, the preferred option in ISO14044, has been used in this study. This assumption means the use of systems expansion is equivalent to allocation on a mass basis between different grades of kiwifruit.

Primary and secondary data

The ISO 14040 series of LCA standards recommend that site-specific data (and/or representative averages) should be used where possible (ISO14044, section 4.2.3.6.3) and lists relevant aspects of data quality (ISO14044, section 4.2.3.6.2). Primary (i.e. site-specific) data should be used wherever possible in a study to maximise its legitimacy and, therefore, whenever possible, primary data have been used in this exploratory study. For example, this study uses primary data for the orchard and packhouse/coolstore life cycle stages. However, secondary data sources, including reports in the literature, are used to complete calculations of the water footprint for the UK parts of the supply chain.

Data quality

Data quality is a critical issue in LCA studies. It includes the following aspects of data: time-related coverage, geographical coverage, type of technology, variability of data values, completeness, representativeness, consistency, reproducibility, sources, and uncertainty (ISO14044, section 4.2.3.6.2).

Koehler (2008) and Milà i Canals et al. (2009) have both noted that the background LCA databases commonly used, such as ecoinvent v2.2 or GaBi, tend to contain only total water abstraction figures rather than freshwater consumptive use figures. Often data for freshwater use are in a background process and not listed. The problems associated with the quantity and quality of data within these two databases in regard to water footprinting are documented in the findings of Berger and Finkbeiner (2010). A major problem encountered during the project in respect to data was that primary and secondary data for compiling freshwater consumptive use inventories for each life cycle stage are currently limited.

In many cases, figures stated for blue water within the literature often had differing inputs and covered a range of different scopes. For example, blue water figures for electricity generation often include grey water. Alternatively, the literature often cites a total water consumption figure alone rather than distinguishing between different types of consumptive water use. In many cases it was impossible to separate different water types, which led to underestimation or overestimation of the water footprint.

Uncertainty

A measure of uncertainty has not been included in this study because the combination of different uncertainties is often mathematically impossible to calculate and, even in cases when it is possible to measure, the methods used are often not theoretically sound; this is consequently an active area of research and development of the LCA method (Reap et al. 2008).

5 Orchard production

The approaches used to provide an inventory of freshwater consumptive use in the orchard life cycle stage are described in this section. The data presented are for green kiwifruit, given that data related to the production of gold kiwifruit were separated and removed during the analysis.

5.1 The orchard survey

Data on kiwifruit production and freshwater consumptive use collected from surveys from 10 growers were used to check crop water-use models and actual irrigation water use. They also provided additional data on spray and frost-protection water use. These surveys, based on data provided by Zespri™ on yields and spray diaries and also on the orchard's irrigation scheduling service, included either face-to-face or over the phone discussions with the growers. The survey work was completed between February 2010 and May 2010. Additional data were provided by representatives of Fruition Horticulture.

Each of the orchards included in the survey had a rain gauge and several soil moisture monitoring sites. Each monitoring site has a water meter and three tubes that allow the soil moisture to be monitored every 10 cm down through the soil profile to 1 m; readings were taken weekly for the previous four years.

5.2 Rainfall

Rainfall is recorded weekly on the 10 surveyed orchards. Effective rainfall (rain that is likely to infiltrate the soil and not drain below the root zone) is calculated as the weekly rainfall less the first 5 mm (less than 5 mm is unlikely to infiltrate the soil and be used by the plant) and less any rainfall beyond field capacity. While the total rainfall is assumed the same across an orchard, effective rainfall will vary depending on the soil moisture. For example, in the

2009/10 season one orchard had total rainfall during the irrigation season of 147 mm; however, the effective rainfall in different parts of the orchard varied between 78 and 110 mm.

Table 1 shows the average rainfall across three seasons in millimetres (mm) and litres per tray. A tray refers to the orchard production of Class I fruit at the first pack at the orchard rather than a tray (tray equivalent or TE) leaving the packhouse.

One of the irrigation management goals is to maximise the use of rainfall, however, there needs to be a balance between maximising effective rainfall (low soil moisture levels) and preventing plant water stress (higher soil moisture levels). While in theory soil moisture should be maintained at around 50% of the soil's available water-holding capacity for most of the irrigation season, in reality it varies across the orchard. Effective rainfall depends on the soil water-holding capacity; no irrigation is assumed to be lost, i.e. the irrigation water component is 'effective' irrigation. In one orchard the effective rainfall varied between 53% and 75% of the total rainfall during the 2009/10 season.

Table 1 Surveyed green kiwifruit orchards effective rainfall and irrigation in mm

		units	2009/10	2008/09	2007/08	2006/07	3-year rolling average
Total rainfall (green)	average	mm	220	294	205	420	239
Effective rainfall (green)	average	mm	151	154	119	254	141
Irrigation (blue)	average	mm	147	123	137	156	136
Irrigation season effective rainfall and irrigation	average	mm	298	277	256	409	277
	Min	mm	152	162	160	341	152
	Max	mm	361	345	371	451	371

5.3 Irrigation

While all the selected orchards had water meters, read weekly as part of an irrigation monitoring service, on closer analysis it was found that some had developed faults. (An example end-of-season report is included in Appendix 2.) In one instance electricity-use records were needed to estimate the water use. Several other orchards had meter problems that required them to be replaced at various times over the four years. This often meant that spring and autumn readings produced an error and that season's irrigation had to be excluded from the analysis.

Orchards are separated into irrigation stations with different quantities of water applied to each station. Recording the irrigation water applied using a meter before the first takeoff would establish the average water applied. Significant variations occur across the orchard, for example, one surveyed orchard applied an average of 310 mm but between 235 mm and 380 mm to different parts of the orchard. However, for this awareness-raising study the average figure was sufficient to determine the orchards' irrigation input. Table 2 shows irrigation data from the orchard survey in litres per tray. A tray refers to the orchard production of Class I fruit at the first pack at the orchard rather than a tray (tray equivalent or TE) leaving the packhouse.

Table 2 Surveyed green orchards effective rainfall and irrigation in l/tray (a tray is Class I fruit at the 1st pack)

		Units	2009/10	2008/09	2007/08	2006/07	3-year rolling average
Effective rainfall (green)	average	l/TE	194	166	145	336	168
Irrigation (blue)	average	l/TE	177	132	175	196	161
Irrigation season effective rainfall and irrigation	average	l/TE	371	298	320	532	330
	Min	l/TE	159	173	205	445	159
	Max	l/TE	561	376	618	689	618

There is a poor correlation (r^2=0.17) between irrigation and effective rainfall as shown in Figure 2, although, as would be expected, it generally shows higher irrigation where there was lower effective rainfall and vice versa. The correlation is improved (r^2=0.29) when one orchard with consistently low irrigation inputs is removed. Management style and the capacity of the irrigation system are likely to have the most influence on the amount of irrigation water used.

No correlation was found between irrigation and production. This analysis was done by overlaying production and irrigation inputs across a single orchard, thereby minimising the influence of management and the irrigation system. Irrigation and soil moisture are only part of a complicated myriad of factors that influence plant production. As soil type, microclimates, plant management, and variability all have significant influences on orchard production, irrigation could not be isolated as a single variable to predict production.

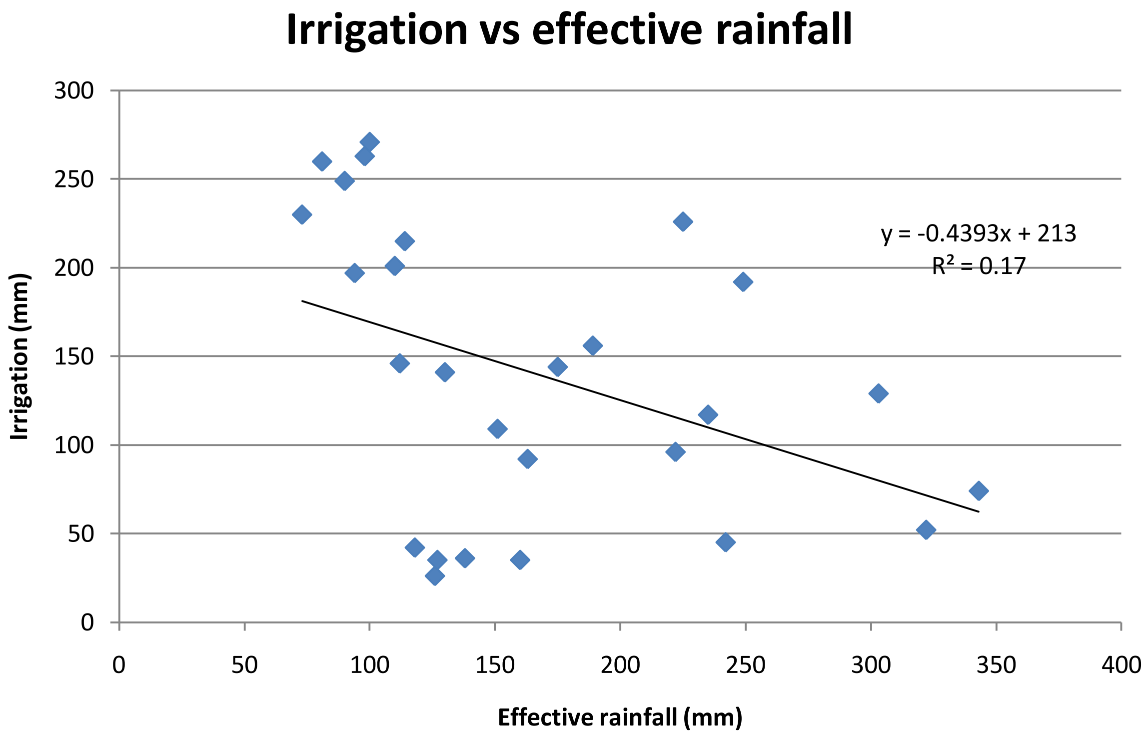


Figure 2 Effective rainfall and irrigation for surveyed green kiwifruit orchards' growing season.

5.4 Yields

Zespri™ provided the production Inventory Reports of the 10 surveyed orchards for four seasons between 2006/07 and 2009/10; see Appendix 1 for an Inventory Report example.

These Inventory Reports included the number of Class I (export) TE at the first pack (Gross submit). A tray equivalent (TE) is a unit of volume measurement based on a single-layer tray of kiwifruit, with an average fruit weight of 3.3 kg. Based on the orchard size this was converted into the yield in trays per hectare. This is the production figure that growers most typically use to describe the yield from an orchard. The Gross submit includes fruit classified as Non Standard Supply (NSS) small fruit (size 42). Where the results from the 10 surveyed orchards are presented as water use per tray, the orchard's production in TE as measured by their Gross submit is used.

The Inventory Report also includes Class I fruit losses while in storage at the packhouse. Fruit that is packed and then held in storage is subsequently inspected and fruit that may have deteriorated in storage is regraded and repacked. Fruit that is rejected as Class I may then be graded and marketed as Class II kiwifruit and sold into the domestic New Zealand market.

Fruit that is neither Class I nor II is classified as waste fruit and either used as stockfeed or sent to a landfill. Data were not available on how much of the orchard production was classified as waste fruit. However, it was assumed that 10% of the fruit received from the orchard was waste fruit (D. Smith, pers. comm., 22 May 2008), rejected at either the first pack or subsequent repack. Table 3 shows the average orchard yields and subsequent number of trays sent from the packhouse of the 10 surveyed orchards.

The difference between Class I fruit at the 1st pack and Class I fruit shipped for export is fruit losses in storage. The 3-year average storage losses for green fruit were 4.8% of the Gross submit. In the current 2009/10 season, because at the time of preparing this report some of the kiwifruit had only just been packed, storage losses have not yet occurred. In these cases storage losses were estimated based on the previous season's average losses.

Table 3 Average green orchard production (TE per hectare)

Season	Class I Export (1st pack, Gross submit TE)	Class I Export (shipped)	Class II	Total trays sent from packhouse
2009/10	8505	7980	383	8363
2008/09	9283	9105	268	9372
2007/08	8325	7703	275	7978
2006/07	8090	7250	247	7497
3 year rolling average (2010-2008)	8705	8263	309	8571

5.5 Water use in winter

To clean the lines and check the system before the start of the irrigation season, water may be pumped through the irrigation system and used for frost control, where sprinklers are raised above the canopy. Emerging buds or new spring growth can be protected by freezing a protective layer of ice around the canopy and vines. As the air temperature drops, the plant temperature remains the same as heat is released from the freezing water.

Another use of water in winter could include flushing the irrigation lines before starting the new irrigation season. Table 4 shows the average water use before starting irrigation for the surveyed green kiwifruit orchards. The 10 surveyed orchards were separated into those with irrigation system frost protection and those without.

Table 4 Green kiwifruit spring frost protection and line flushing

	Units	2009/10	2008/09	2007/08	2006/07	3-year rolling average
Total winter water use (survey average)	mm	40	16	30	17	29
	l/TE	50	16	34	20	34
	% of water applied[1]	21%	9%	21%	12%	16%
Frost and flushing	mm	59	23	42	32	43
	l/TE	74	24	48	37	51
	% of water applied	30%	14%	15%	20%	20%
Line flushing	mm	2	2	5	2	3
	l/TE	2	2	6	3	3
	% of water applied	2%	2%	2%	3%	2%

[1] The quantity of water used for frost control as a percentage of the total water applied (irrigation, frost control, and spraying)

5.6 Electricity

The intention had been to collect electricity use data from the surveyed growers; however, this proved too difficult, given the surveys were conducted over the harvest period and difficulties were experienced collecting other more critical orchard data.

In the study conducted by Mithraratne et al. (2010), average electricity use on irrigated orchards was 2000 kWh/ha, although the variability was very large, with the 95% confidence interval being ± 1400 kWh/ha.

In this project one orchard was able to provide electricity use that averaged 815 kWh/ha for the 3 seasons between 2007/08 and 2009/10. Several electricity and water meter readings taken over the period of 1 hour varied between 2.7 and 2.9 m^3 pumped per kWh. Over a 10-month period between June 2009 and April 2010 water and electricity use averaged 2.5 m^3/kWh.

Water use per kilowatt hour is very orchard specific. As a rough guide, by averaging electricity and water use, acknowledging they are taken from different orchards and seasons, 2450 m^3/ha (Table 6, 245 mm) and 2000 kWh/ha equates to 1.2 m^3/kWh. This suggests the individual orchard that was monitored for both water and electricity use may be at the higher end of water use per unit of electricity. This would also be expected, given that this particular orchard takes water from a deep aquifer.

5.7 Agrichemical and foliar fertiliser spray applications

The application of agrichemicals and foliar fertilisers is recorded in an electronic spray diary. The spray diaries of three Green orchards were analysed for the 2009/10 and 2008/09 seasons. The results are shown in Table 5. The quantity of water used averaged 8000 l/ha for green kiwifruit. This was just 0.6% of the irrigation water applied to the green kiwifruit.

Table 5 Water and agrichemical use on Green kiwifruit orchards (2-year average)

	Units	green kiwifruit
Water	l/ha	8,000
	l/TE	0.9
Agrichemical & foliar fertiliser	l/ha	53
	ml/TE	6.2

6 Packhouse and coolstore

Data and the approach used to provide an inventory of freshwater consumptive water use in the packhouse and coolstore life cycle stage are described in this section.

6.1 The packhouse and coolstore survey

The packhouse and coolstore survey was carried out in May and June 2010 and builds on experience in previous work with the New Zealand kiwifruit, pipfruit and berryfruit industries. The survey consisted of sending a written survey to the three packhouses and coolstores involved, and then visiting the packhouses and coolstores in person to explain the background of the project and to gather data. Targeted follow-up work was completed by contacting the packhouses and coolstores by email and telephone. A copy of the packhouse/coolstore survey forms is provided in Appendix 3.

The three operators included in the survey consisted of combined packhouse and coolstore facilities. Each packhouse stored packed kiwifruit in their coolstores. Of 92 coolstores that stored kiwifruit in 2008/09, 48% stored less than 500 000 TE, 17% stored between 500 000 and 1 Million TE, 14% stored between 1 and 2 Million TE. Some 21% stored more than 2 Million TE. On average, each coolstore stored 1 189 000 TE. The three coolstores surveyed typically stored more than 2 Million TE of kiwifruit. The amount of kiwifruit stored indicates the surveyed packhouse/coolstores were representative of the kiwifruit industry.

The kiwifruit year 2009/10 extends from 1 April 2009 to 31 March 2010 (Zespri 2009), and it is for this period that data were collected during the survey. The survey data covered two kiwifruit varieties, Zespri Green and Zespri Gold. Whilst details of gold kiwifruit were collected explicitly to clarify allocation of freshwater consumptive use between the two products, data for gold kiwifruit have been not been listed in the pages below because only green kiwifruit fall within the scope of this report. The survey provides data for the kiwifruit year 2009/10. The kiwifruit year 2009/10 extends from 1 April 2009 to 31 March 2010 (Zespri 2009). Data were collected for this period during the survey.

The facilities of packhouse/coolstore No. 1 (PHC1) and packhouse/coolstore No. 2 (PHC2) were near Mt Maunganui and packhouse/coolstore No. 3 (PHC3) near Te Puke. The majority of New Zealand kiwifruit production is located in the areas of Te Puke and Tauranga. In 2008/09 (the latest figure available at the time of writing) the orchards in Tauranga and Te Puke had a total of 6725 producing ha, or 53% of the total Zespri green kiwifruit production area. In 2009/10 the packhouses PHC1, PHC2, and PHC3 together received about 16% of the total amount of kiwifruit submitted to New Zealand packhouses. Again, this shows the packhouse/coolstore survey is a representative sample of the sector.

6.2 Transport of kiwifruit to the packhouse and coolstore

In 2008/09, kiwifruit were submitted to 71 packhouses and, after grading and packing, stored in 92 coolstores. In total 109 386 000 TE were submitted, of which 71% were green kiwifruit. Each kiwifruit orchard submitted on average 37 876 TE, with an average yield of 8866 TE per ha (Zespri 2009).

While some packhouses are located within an orchard, the majority of kiwifruit are graded and packed in off-orchard locations. The transport of kiwifruit between orchard and packhouse uses diesel fuel, and the diesel will have an associated water footprint related to its production. After picking, kiwifruit are transferred into 45-kg (empty weight) wooden bins, and these contain approximately 260 kg fresh fruit (305 kg total bin weight). Typically, an 11.5-t truck and trailer is loaded with about 66 bins. The kiwifruit is delivered to the packhouse, and returns empty to the next orchard (Fisher, pers. comm., 27 May 2010; Humphries, pers. comm., 28 May 2010; Allison, pers. comm., 28 May 2010). In our survey the average transport distance (one way) was 25–30 km in the Tauranga and Te Puke area. A small amount of kiwifruit came from orchards that were further away. For example, PHC 1 received about 2300 bins, approximately 7% of total number of bins for this packhouse, from Hastings in Hawke’s Bay. Table 6 shows the details of transport to the surveyed packhouses and coolstores.

Table 6 Details of transport of kiwifruit from orchard to the surveyed packhouses and coolstores for the 2009 kiwifruit harvest

Item	PHC1	PHC2	PHC3
Means of transportation	11.5-t truck and trailer		
Average freight	66 wooden bins[1]/truck and trailer		
Average distance (one way) orchard to packhouse	30 km	30 km	25 km
Total number of bins received	47200	67 320	99 000
Empty on return trip?	Yes	Yes	Yes

[1] The weight of an empty wooden bin is 45 kg. It is filled with approximately 260 kg fresh kiwifruit.

6.3 Packhouse operations

The processes involved in the industrial production of cardboard and plastic packaging use freshwater. In an LCA it is typical to consider all relevant data that could affect freshwater consumption over the life cycle of a product. This section investigates the water footprint of the packaging materials used for packing green kiwifruit.

In this life cycle stage it is important to distinguish between the green kiwifruit that arrives from the orchard and the green kiwifruit that is packed, is placed in coolstore, and leaves the coolstore for export to the UK. As highlighted in Table 3, the difference between Class I fruit at the 1st pack and Class I fruit shipped for export are fruit losses in storage at the packhouse and coolstore before the shipment of fruit to market.

In section 5, the term '1st pack' is used to describe the kiwifruit that were submitted by an orchard to the packhouse/ coolstore before any grading into different classes (e.g., Class I and Class II) was undertaken. Class I kiwifruit are sold for export and Class II kiwifruit are sold into the New Zealand domestic market. In this section the term 'kiwifruit submitted' is used and is the same as the '1st pack'. The term 'kiwifruit delivered' is used to describe the graded and packed kiwifruit that leave the packhouse and coolstore to enter the next phase of their life-cycle (e.g., New Zealand port).

Kiwifruit are packed into different sized cardboard boxes according to the specifications of five different pack types. The cardboard for the boxes is manufactured in New Zealand and supplied by three different producers, Carter Holt Harvey, Amcor, and Visy Board. The boxes are assembled in the packhouse when required.

The kiwifruit are submitted to the packhouse in wooden bins (Figure 3,❶). Kiwifruit are often left to stand for approximately two days. This two-day standing process is called 'curing' and in these two days the fruit lose field heat. The kiwifruit from the bins are then carefully tipped onto a conveyor belt (Figure 3,❷).

From the conveyor belt the kiwifruit are transferred onto the grading tables, where they are graded by hand (Figure 3,❸). Class I fruit are transferred from the grading table to another conveyor belt for export packing. The Class II fruit are removed by hand and transferred to a different, smaller conveyor belt; and waste (neither Class I nor Class II) kiwifruit are discarded into a tube-like chute (Figure 3,❹). From the chute the waste kiwifruit are transferred on another conveyor belt into wooden bins. The waste kiwifruit are sold either to farmers as cattle feed, or for processing. Processing involves making kiwifruit into puree that is later exported as ingredients for finished food items such as jam.

The Class I fruit are individually labelled (Figure 3,❺), weighed, and packed according to one of five different packing specifications (Figure 3,❻). The trays or boxes with kiwifruit are packed onto wooden pallets and stabilized with plastic strapping (Figure 3,❼). Pallets of kiwifruit are stored in a coolstore awaiting onward transport, for example, to the port for export (Figure 3,❽). Before export the kiwifruit are inspected, any degraded fruit are removed, and boxes or trays are repacked, if necessary.

For the estimation of the water footprint we followed the methodology outlined in Milà i Canals et al. (2009) using the data from the survey, and additional information (e.g., detailed specification of pack types) from Zespri™, and via the use of Life Cycle Inventory (LCI) databases (Australian Life Cycle Inventory Data Project, ecoinvent database V2.2).

Grading of kiwifruit

The key results from the grading, packing and delivery of kiwifruits in 2009/10 for the surveyed packhouses are summarised here and in Table 7:

- On average, 85.3% of green kiwifruit submitted to the packhouses were graded and delivered as Class I kiwifruit
- On average, 3.7% of green kiwifruit submitted to the packhouses were graded and delivered as Class II kiwifruit
- On average, 10.4% of green kiwifruit submitted to the packhouses were utilized as stockfeed.

Figure 3 Overview of the packing process for kiwifruit.

Table 7 Grading results for green kiwifruit for surveyed packhouses for the year 2009/10 in tray equivalents (TE). The average of the three packhouses and the respective standard deviation is given

	Units	PHC1	PHC2	PHC3	Average (Std dev)
Zespri green kiwifruit – submitted	Tray equivalent (TE)	3 300 000	3 500 000	7 007 588	-
Class I delivered	TE	2 940 000	2 930 000	5 807 764	-
Amount of Class I of submitted	%	89	84	83	85.3 (3.2)
Class II delivered	TE	264 000	0	207 407	-
Amount Class II of submitted	%	8	0	3	3.7 (4)
Stockfeed delivered[1]	TE	39 600	571 428	992 417	-
Amount stockfeed of submitted	%	1.2	16	14	10.4 (8)
Process kiwifruit[2]	TE	59 400	0	0	-
Amount process kiwifruit of submitted	%	1.8	0	0	0.6 (1)
Waste to Landfill	TE	0	0	0	-

[1]: PHC1 and PHC2 sold their stockfeed kiwifruit for 3.5c per TE. PHC3 received no revenue for kiwifruit sent for stockfeed.

[2]: PHC1 received 10.5c per TE sold for processing. Processing involves pureeing of kiwifruit.

Pack types

Five packing methods were used for kiwifruit in the year 2009/10:

- International tray (IT)
- Modular loose box (ML)
- Modular double box (M2)
- Modular bulk box (MB)
- Plateau box (P1)

The different packing types contain different amounts of kiwifruit, ranging from 3.6 kg for the pack type IT, to 10 kg for the pack type MB. The pack types IT and P1 use a polyliner (called a Plix) and a pocket pack, while the pack types ML and MB only use one polybag. The pack type ML uses a polybag and two pocket packs, as shown in Table 7. Figure 4 shows examples of plateau and modular boxes used for packing Class I kiwifruit.

Figure 4 Left: A plateau box (packing type P1). The green kiwifruit rest on a polyliner (Plix) and are covered by a pocket bag. Right: A modular bulk box (packing type MB), the kiwifruit are inside a polybag.

The ratio of fresh kiwifruit weight to the weight of packing materials is different for the various pack types. For example, the kiwifruit weight to cardboard weight ratio is 17.4 for the pack type MB and 11:1 for the pack type IT.

The weight of the cardboard per box or tray also depends on the manufacturer (J. Clendon, pers. comm., 3 June 2010). For example, the modular bulk box of the pack type MB weighs 490 g box, 590 g box, or 645 g box if it is produced by Carter Holt Harvey, Amcor or Visy Board, respectively. For this survey an average of all three manufacturers was included, as shown in Table 7. The data were provided by Janet Clendon Global Packaging Manager for Zespri (J. Clendon, pers. comm., 3 June 2010).

Table 8 Packing components of the various green kiwifruit pack types

	Dimensions in mm	No. of Tray or Box	Average weight of tray/box (min-max)[1] in g	No. of Polyliner (Plix)[2]	No. of Polybags[3]	No. of Pocket packs[4]
International tray (IT)	300*300*69	1	325 (322–445)	1	-	1
Modular loose box (ML)	300*400*121	1	425 (390–505)	-	1	-
Modular double box (M2)	300*400*121	1	425 (390–505)	-	1	2
Modular bulk box (MB)	300*400*189	1	574 (490-645)	-	1	-
Plateau box (P1)	600*400*69	1	419 (430–535)	1	-	1

[1:] The weight of trays and boxes varies depending on the manufacturer. Trays and boxes used for kiwifruit in New Zealand are manufactured by Visy Board, Amcor, or Carter Holt Harvey. The packhouses could not identify the manufacturer(s) for the pack types they used. Therefore, an average weight was used.
[2:] Polyliners are supplied in units of 4000 polyliners. The weight of each unit (4000 liners) is 22 kg.
[3:] Polybags are supplied in units of 1000 polybags. The weight of each unit (1000 polybags) is 13 kg.
[4:] Pocket packs are supplied in units of 500 pocket packs. The weight of each unit (500 pocket bags) is 12 kg.

The different pack types are fixed on to pallets in either Hi-cube or standard arrangement. The number of boxes, or trays, per pallet differs between the Hi-cube arrangement and the standard packing arrangement. The Hi-cube arrangement holds a higher numbers of boxes or trays. For example, the standard pallet of pack type MB consists of 100, and the Hi-cube of 110 modular bulk boxes. Figure 5 shows a typical pallet arrangement for green kiwifruit. Irrespective of the pack type (IT, MB, ML, M2, P1) or pallet type (standard or Hi-cube), the materials listed below are needed to assemble a pallet of boxes or trays:

- About 30 m of polypropylene (PP) strapping is needed per pallet. The strapping is purchased in rolls. One roll of strapping contains 1000 m of strapping and weighs 10.88 kg/roll
- The boxes or trays are protected against damage from the strapping by four V-boards made from cardboard
- The top row of boxes or trays is protected by a wooden cap,weighing 3 kg. On top of the wooden cap a cardboard cap which weighs 0.3 kg.

Figure 5 A standard height pallet packed with modular bulk boxes (pack type MB). The boxes are placed on a wooden base pallet and are stabilised by PP strapping. Damage by the strapping to the boxes is prevented by four V-boards (corner boards). The top row of boxes is protected by a wooden cap (not visible in the figure) and a cardboard pallet cap.

The majority of green kiwifruit, 68% of Class I kiwifruit, was delivered in the MB pack type as shown in Table 8. The second most common pack type was IT. IT packs accounted on average for 18% of class green kiwifruit. The majority (73%) of kiwifruit exported to Europe is in the MB pack type, while the majority (48%) of kiwifruit exported to Japan is of the pack type IT as shown in Table 10 (J Clendon, pers. comm., 3 June 2010).

Using information in Table 7 (graded green kiwifruit), Table 8 (pack specifications, Table 9 (distribution of pack types), and Table 10 (details of the export markets), the amounts of materials used for packing was calculated and is shown in Table 11. After discussion with the staff at the three packhouses, a wastage rate of about 5% was assumed for all packing materials. Therefore, 5% was added to the calculated amounts of packing materials.

Table 9 Distribution of pack types containing Class I green kiwifruit and delivered by the three packhouses

Pack type	Percentage of Class I green kiwifruit delivered			
	PHC1	PHC2	PHC3	Average
International tray (IT)	18	18	19	18
Modular loose box (ML)	0	0	0	0
Modular double box (M2)	2	7	5	5
Modular bulk box (MB)	68	63	74	68
Plateau box (P1)	7	12	2	7

Table 10 Details of the export green kiwifruit in the various pack types and their share of the European and Japanese market for the year 2009/10

Type of pack unit	Avg. weight of fruit per pack (kg)	Pack units per pallet (standard)	Pack units pallet (Hi-cube)	% Share of Market Europe	% Share of Market Japan
International tray (IT)	3.597	232	256	0	48
Modular loose box (ML)	5.667	160	180	12	23
Modular double box (M2)	5.5	160	180	6	0
Modular bulk box (MB)	10.02	100	110	73	28
Plateau box (P1)	5.6	145	145	7	0

Table 11 Estimated consumption of packing materials for delivering Class I green kiwifruit in 2009/10 by the surveyed packhouses. A 5% wastage level for all materials is assumed, with the exception of wooden bins, and photocopier/printer paper

		PHC1	PHC2	PHC3
Item	*Material*	Total quantity for Zespri green kiwifruit (kg)		
Trays, boxes	Cardboard	687 945	736 804	1 421 127
Cardboard pallet caps	Cardboard	3339	3550	6885
Polybags, pocket packs	HDPE	28 854	36 365	62 238
Polyliners (Plixes)	PET	3820	4350	6829
Strapping	PP	8246	8376	17 263
Pallets	Wood	278 321	295 861	573 714
Bins	Wood	46 530	35 145	38 565
Wooden pallet caps	Wood	33 399	35 503	68 846
Photocopier, printer paper	Paper	870	Unknown	1 750

6.4 Direct water use, fuel and electricity

The surveyed packhouses provided the total amounts of water, fuel, and electricity consumed for packing kiwifruit in the year 2009/10. A mass allocation rule was used to separate the direct water use, and fuel and electricity inputs for the different grades of kiwifruit. The results are given in Table 12. In Table 13 the average and standard deviation of direct water use and fuel and electricity use per TE of Class I green kiwifruit delivered by the packhouses is given for inputs where results from all three packhouses were obtained, otherwise only the average is given.

Two of the packhouses had a water meter installed (PHC1 and PHC2), while PHC3 had no water meter installed. It was therefore only possible to use the data from PHC1 and PHC2 for estimating the direct water-use per TE of Class I green kiwifruit.

In both PHC1 and PHC2 a single water meter was fitted that covered both packhouse and the coolstore operations. After consultation with the staff of PHC1 and PHC2 it was assumed 60% of direct water use was in the packhouse and the remaining 40% was used in coolstore operations. The packhouse and coolstore water-use data is separated in this study to help facilitate the discussion of potential options for reduction of freshwater consumption in each of those separate operations in the wider research project. In a limited number of cases kiwifruit may be packed and stored at different locations and therefore it may be necessary to split the two operations in the future.

It can be questioned whether the direct and indirect water use by staff should be included in the water footprint calculations. There is no clear guidance in the WFN method on this aspect. However, in a LCA study the activities related to labour, e.g., for indirect water use activities happening outside packhouse/coolstore site such as workers commuting, are usually excluded from the data because of conflicts between environmental and social impacts. Indirect water use at the packhouse/coolstore of the nature just described is excluded from the study. Direct water use by staff includes the use of toilets, washing hands, and water use for cooking and drinking; data were available for PHC1 and PHC2 and is included in this study.

Data from the survey included details of how many employees worked in the packhouse and the length of time they were involved in packing activities. In PHC1, 200 staff worked for 60 days over the main packing season, and some 100 staff worked for 40 days packing kiwifruit stored under controlled atmosphere. A further 45 people worked for 80 days on repacking and 20 people for 80 days for other activities. In PHC2, 300 staff worked for 60 days for the main packing season and 30 staff for 200 days for various activities, including repacking. The total number of staff working days was calculated then multiplied by 25 litres to provide a figure for direct water use by staff. Direct water use by staff accounted for the majority of the direct water use in the packhouse with 72% in PHC1, and 81% in PHC2.

The remainder of the direct water use is mostly for cleaning, for example, during water-blasting of the wooden bins. The direct water use for water-blasting wooden bins was estimated by assuming that each wooden bin was water-blasted for 1 minute. This assumption is based on estimates by the packhouse staff. A water flow rate of 500 l/h is also assumed for direct water use by the pressure washer used in cleaning. The flow rate is an average value for a high-pressure commercial cleaner models sold by Kärcher (Kärcher New Zealand 2010).

Fuel use was predominately diesel use for forklifts, vehicles involved in client relations, and for the vehicles of field staff. Liquid Petroleum Gas (LPG) is also used in forklifts. A limited amount of petrol was used in cars involved in packhouse administrative jobs. Lubricants are also used for greasing machinery used to assemble cardboard boxes and for the grading and packing of kiwifruit.

All three packhouses had one electricity meter for both the packhouse and coolstore operations. After consultation with the packhouse and coolstore staff, a split of 20% use in the packhouse and 80% use in the coolstore was assumed. The packhouses provided the total electricity for the period in which kiwifruit are packed and stored (March–September). The electricity in the packhouse is used for operating machinery associated with grading and packing and for the lighting of storage and grading facilities.

Table 12 Direct water, fuel, and electricity consumption for Class I green kiwifruit delivered by surveyed packhouses

	PHC1	PHC2	PHC3	Average (Standard deviation) per TE of Class I kiwifruit delivered
	Direct water use for Class I green kiwifruit (m^3)			(l/TE)
Staff water use (25 l/person and day)	498.2	426	Unknown	0.157
Water blasting of wooden bins	101.5	58.9	Unknown	0.027
General cleaning	95.9	42.6	Unknown	0.024
Total	695.6	527.5	Unknown	0.208
	Fuel use for Class I green kiwifruit (l)			(l/TE)
Diesel	1353.6	532.5	2005	0.0003(0.0001)
Petrol	6016	Unknown	1540	0.0008
Lubricants (Silicone)	Unknown	142	Unknown	1.6E-05
LPG (kg)	5264	1775	3287	0.001(0.0007)
	Electricity use for Class I green kiwifruit (kWh)			
Total	285 300	349 204	666 504	0.110(0.01)

6.5 Coolstore operations

After grading and packing, Class I green kiwifruit are transferred into a coolstore room for storage. Some kiwifruit in the coolstores are stored under a low oxygen-content controlled atmosphere (CA) to avoid the adverse effects on fruit quality encouraged by prolonged storage. Before the delivery of kiwifruit to a port for export overseas, they are inspected for any damage, and if necessary any damaged kiwifruit are discarded, and the remainder is repacked.

Both PHC1 and PHC2 stored kiwifruit in CA and non-CA stores, and PHC3 stored kiwifruit only in non-CA conditions. The average storage times at each packhouse are summarised below and in Table 13:

- In the three coolstores Class I green kiwifruit stored without CA are stored between 76 and 205 days with an average of 154 days
- In the three coolstores Class I green kiwifruit stored in CA are stored between 37 and 127 days with an average of 84 days.

The direct water use, and fuel and electricity use at the coolstore are described in Table 14. The average and standard deviation of water, fuel, and electricity use per TE of Class I kiwifruit delivered by the packhouses is given for inputs where results from all three packhouses (e.g., electricity) were obtained, otherwise only the average is given.

Table 13 Storage times with and without controlled atmosphere (CA) conditions for Class I green kiwifruit in the year 2009/10. The average storage times and the respective standard deviations are also given

	PHC1	PHC2	PHC3	Average (Standard deviation)
		Green kiwifruit stored without CA		
Number (TE)	2 263 800	2 080 000	5 807 764	-
Min (days)	213	14	1	76(119)
Max (days)	238	182	196	205(29)
Average (est. days)	225	126	112	154(62)
		Green kiwifruit stored with CA		
Number (TE)	676 200	850 000	0	-
Min (days)	60	14	-	37
Max (days)	100	154	-	127
Average (est. days)	80	88	-	84

Table 14 Water, fuel, and electricity consumption for Class I green kiwifruit delivered in the coolstore

	PHC1	PHC2	PHC3	Average (Standard deviation) per TE of Class I kiwifruit delivered
Direct water use for Class I green kiwifruit (m^3)				(l/TE)
Staff water use (25 l/person and day)	Attributed to packhouse	Attributed to packhouse	Attributed to packhouse	Attributed to packhouse
Water blasting of cool rooms	94	71	Unknown	0.028
Rest (general cleaning)	384	281	Unknown	0.113
Water footprint from direct water use[1]	23.9	17.6	Unknown	0.007
Total	478	352	Unknown	0.141
Fuel use for class 1 ZESPRI® GREEN kiwifruit (l)				(l/TE)
Diesel	0	1598	8022	0.0006 (0.0007)
Petrol	9.4	0	6160	0.0004
Lubricants (Silicone)	0	0	0	0
LPG (kg)	2256	5325	13 149	0.002 (0.0008)
Electricity use for class 1 ZESPRI® GREEN kiwifruit (kWh)				
Total	1 476 531	1 396 821	2 666014	0.479 (0.022)

[1] The evaporative losses of direct water use were assumed to be 5% as per the estimate used by Canals et al. (2010) for evaporative losses of direct water use in processing.

In a recent report by the New Zealand Energy Efficiency and Conservation Authority (EECA) and Zespri™ in 2008 the electricity use of six coolstore facilities ranged from 0.38 kWh/TE to 0.49 kWh/TE, with an average of 0.44 kWh TE (Bollen 2009). In the electricity consumption figures given in Table 14, electricity use was 0.48±0.02 kWh TE for Class I green kiwifruit. The survey results are therefore within the range of values reported in Bollen (2009).

7 Post packhouse/coolstore life cycle stages

For these life cycle stages data have been taken from the previous kiwifruit supply chain carbon footprinting exercise (Mithraratne et al (2010) when appropriate. However, only inventory data that might be considered relevant for inclusion in the water footprint have been listed in this section.

7.1 Port operations

Once Class I green kiwifruit are ready for export the packed kiwifruit is removed from coolstore and transported to the shipping port. The pallets are transported by 40-t trucks (without refrigeration) from the packhouse/coolstore to port, and the trucks return empty. Typically, a truck carries 24 pallets, travelling an average 40 km in each leg of the journey. The truck is empty on the return leg of the trip from the port. In Mithraratne et al. (2010) electricity use at the port was estimated at 0.012 kWh TE, and this figure is used in this study.

7.2 Shipping

Data for shipping was taken from Mithraratne et al. (2010) for use in this study. For the European market, about 90% of the fruit is shipped in pallets in REFA bulk ships (i.e. stored below deck) to Zeebrugge; the remainder is transported in containers on deck. The distance from Tauranga in New Zealand (departure port) to Zeebrugge (destination port) in Belgium is 20 675 km. Typically, the weight of a kiwifruit pallet containing 174 TE of fruit is 727 kg and a ship to Europe carries 5250 pallets. It is estimated that a ship consumes 50 t marine diesel per day (including auxiliary power for cooling), and it is assumed the ship brings miscellaneous items from Europe back to New Zealand.

The actual fuel use for kiwifruit transport to Europe is calculated as follows:

Total fuel use by the ship to travel 20 675 km from Tauranga to Zeebrugge in Belgium is 1300 t of marine diesel. The ship carries 5250 pallets, each with 174 TE of fruit with a gross weight of 727 kg. Therefore, the total weight of goods transported is 3816.75 t.

The fuel use intensity to Europe = 1300 ÷ (20796 × 3816.75) = 0.0000164 t/t-km = 0.0164 kg/t-km.

The ship was assumed to be fully loaded on the return journey, and emissions in the backhaul were not considered.

7.3 Repacking in Europe

At the destination port, fruit are unloaded, checked, and may be repacked into single-layer trays, loose bulk, or into six-pack containers. The packed fruit are then stored on average for 18 days before onward transport. For this study (as with Mithraratne et al. (2010)), no data were available for energy use at the port or repackaging facility. A spife is often added to packing at this stage. One spife is added for every ten kiwifruit in the tray. Each spife weighs

15 g and is made of polystyrene. From Zeebrugee kiwifruit is shipped across the English Channel to the UK.

7.4 Transport to the retailer

Fruit are transported by trucks onwards to many European port destinations, including the UK. Obviously transport distances vary widely depending on the final destination for the kiwifruit around the UK. In Mithraratne et al. (2010), distribution distances for kiwifruit in the UK had previously been estimated as 176 km by heavy goods and 98 km by light goods vehicle, as described in Table 14.

Table 15 Details of transport to retail outlets for green kiwifruit

Item	Transport distance	Source of data
London port to retailer (via Regional Distribution Centre)	176 km by heavy goods vehicle[1] and 98 km by light goods vehicle[2]	Smith et al. 2005, pp. A1–2 (Table A1-1) and pp. A1–6 (Table A1-3)

[1] Distance travelled by 'perishable' and 'other non-perishable' foodstuffs (132 km), adjusted to account for empty trips (25% for food and drink). Data are for 2002. Average load is 10.8 t.

[2] Average distance travelled by light goods vehicles (64 km) adjusted to account for empty trips (35%). These data are from a study in 1992/93. Average load is 0.75 t. Eighty-five percent of LGVs are diesel (Smith et al. 2005, p. A3-1).

7.5 Retailer

Almost all kiwifruit are displayed in non-refrigerated displays at retail outlets (V. Parmentier, pers. comm., 21 July 2008).

Nielsen et al. (2003) give the following Danish values for energy used during retailing of various products in large modern stores that 'meet extraordinary requirements on environmental management':

- For 1 kg potatoes (room temperature storage): 0.03 MJ heat and 0.04 MJ electricity
- For 1 kg pasta (room temperature storage): 0.27 MJ heat and 0.47 MJ electricity

These values include energy used for room heating and lighting; they are based on allocation of energy use according to the exposure area and average flow of each product through the store. The difference in the energy use by the two products is due mainly to the variation in the retention time at the retail outlet. In Mithraratne et al. (2010), the value for potatoes was used as a proxy for this life cycle stage (as the retention time of kiwifruit is more similar to potatoes than pasta).

7.6 Transport from retailer to household

In this study it is assumed that the transport between retailer and household is by passenger car. In the UK 58% of trips are made by car in the UK, the remaining being by walking, bus, or cycling (Petty et al. 2005). Transport distances – and associated freshwater consumptive use – between individual retailers and points of consumption are highly variable as they depend on the behaviour of individual consumers and their geographical location. Therefore, this life cycle stage should only be included as an illustrative measure for footprinting activities. The data in Table 16 are taken from a UK study on food miles (Smith et al. 2005). In this study they are used to raise awareness of potential issues, and to demonstrate a potential worst case scenario for the water footprinting exercise.

Table 16 Details of transport from retailer to home

Item	Relevant data	Source of data
Retailer to home transport	5.5 km each way (carrying 11 kg of shopping) by car	Smith et al. 2005, pp. A1–14, 15

7.7 Household consumption

In this stage green kiwifruit can either be refrigerated or stored without refrigeration. In this study it is assumed most kiwifruit are not refrigerated in the home, and therefore the environmental impacts associated with household consumption arise from waste generation at this life cycle stage. This assumption is consistent with the approach adopted in Mithraratne et al. (2010). There are three relevant aspects here: peelings waste, disposal of over-ripe fruit, and packaging waste. Based on Milà i Canals (2007), all these items are assumed to go to landfill after being discarded.

After consumption and digestion in the body, the remains of food are excreted and usually pass on to a wastewater treatment plant. This life cycle stage is often omitted from food LCA studies but is, in fact, relevant for inclusion (Munoz et al. 2008; Sonesson et al. 2004).

Data in Munoz et al. (2008) calculated 25 l of wastewater and 0.023 kWh electricity were associated with consumption of 985 g of broccoli. The wastewater includes used tap water from flushing the toilet, hand washing and washing towels; the electricity value is related to hand drying. For this study, kiwifruit were assumed to have the same wastewater generation and electricity consumption values as broccoli (per kg).

8 Results – Orchard, Packhouse and Coolstore

In this study results have been calculated for water footprints using WFN and LCA methods. Issues of importance are addressed at the appropriate points in each part of this section. The approach adopted in this research was to calculate figures for the volumetric WFN water footprint and use the blue water footprint calculations as the basis of further investigation by environmental impact assessment using LCA methods. LCA results focus on evaporative blue water losses as the foundation of assessing the environmental impact of freshwater consumption. This method excludes non-evaporated water flows including run-off and drainage, except potential losses in reticulation. As a rule of thumb, in the following pages the WFN results are presented first and the LCA results are provided whenever possible.

Two characterisation factors for the environmental impacts of freshwater consumptive use are provided in the results. First, the impacts are given for the Freshwater Ecological Impact (FEI) LCA impact described in Milà i Canals et al. (2009). Second, whenever possible the evaporative blue water results established were multiplied by the regional water stress index (WSI) produced by Pfister et al. (2009).

Detailed results are presented for the orchard and packhouse/coolstore life cycle stages only. For other life cycle stages e.g. beyond the orchard and packhouse/coolstore stages a lack of relevant data and the current limitations experienced in either the WFN or LCA method have meant only a partial illustrative water footprint could be calculated.

Drawing together data from the orchard survey and the climate, soil moisture and other hydrological modelling from SPASMO, the orchard footprint is examined across different kiwifruit growing regions in New Zealand. In the orchard survey 10 orchard locations were included. Summarised results are provided for the orchards in Northland, Auckland, Kaitai, Tauranga, Te Puke, Whakatane, Waikato, Gisborne, Hawke's Bay, and Nelson. Results for the average national water footprint are also discussed.

8.1 Orchard life cycle stage results

The results for the assessment of the orchard water footprint are provided below. In this section a description of an alternative hydrological perspective method are included. The hydrological perspective is based on a different interpretation of the results of the orchard survey and SPASMO data. The hydrological cycle perspective examines the freshwater use using a hydrological water balance and is not necessarily a WFN water footprint but results from a different interpretation of blue and green water as described below in section 8.2. The WFN water footprint is described in section 8.3 and is based on using a consumptive water use perspective from the WFN manual to calculate the blue and green water footprints.

The main reason why both hydrological perspective and the consumptive WFN water footprint have been included in this research is because of ambiguities in the WFN water footprint manual (Hoekstra et al. 2009). The main problems were encountered in the interpretation of the description of the blue water footprint (see p. 20 of the manual).

The WFN manual states the blue water footprint is an indicator of freshwater consumptive use of blue water, i.e. fresh surface or groundwater used in growing kiwifruit. The term 'consumptive water use' refers in this case to one of the following four situations:

- Water evaporates
- Water is incorporated into a product
- Water does not return to the same catchment area, e.g., it is returned to another catchment area or to the sea
- Water does not return in the same period, e.g., it is withdrawn in a scarce period and returned in a wet period.

The manual goes on to explain that evaporation is generally the most significant component of the blue water footprint and consumptive use is normally equated with evaporation, but the other components should be included when relevant. The blue water footprint measures the amount of available water consumed in a certain period (i.e. not immediately returned within the same catchment). The remainder, the ground- and surface water flows not consumed for human purposes including other irrigation uses, is left to sustain the ecosystems that depend on the ground- and surface water flows (Hoekstra et al. 2009).

The blue water footprint for a process is calculated as:

$$WF_{proc,blue} = BlueWaterEvaporation + BlueWaterIncorporation + LostReturnflow$$

The last component refers to the part of the return flow that is not available for reuse within the same period for withdrawal, either because it is returned to another catchment (or discharged to the sea) or because it is returned in a different period of time flows (Hoekstra et al. 2009).

It is the interpretation of the different components of blue water that differs in the hydrological perspective and WFN water footprint presented in the following pages. In particular, differences in the role played by lost return flow is approached differently in the two perspectives. The remainder of this section begins with results produced by the hydrological perspective and then discusses results from the perspective of consumptive water use. Both the hydrological perspective and the WFN water footprint produce different results and insights into the freshwater consumption during the growth of green kiwifruit. The WFN water footprint data are used as the basis for determining LCA environmental impact.

8.2 Orchard hydrological perspective

The hydrological perspective is based on two criteria:

1. The equations need to represent the entire hydrological system of an orchard in a hydrological 'water balance' to capture the impact of the orchard on the local freshwater resources. For example, all significant processes of an orchard water balance need to be represented, and double accounting of individual terms of the water balance for different water footprints (e.g., green and blue) needs to be avoided. The equations, as is expected for representing any dynamics in physical systems, conserve mass (a mass balance) separately both for the green and blue water sub-systems. The green and blue water footprints are also defined in the sense of a net

change of these mass balances. This then enables direct interpretations in the form of an impact indicator (see Figures 5 and 6).

2. The water footprints of the orchard life cycle stage should, as much as possible, represent the environmental impact of New Zealand's kiwifruit orchard production on the quantity and quality of the water resources in New Zealand.

The criteria follow a recent recommendation by Gupta and van der Zaag (2008), who gave five criteria for evaluating inter-basin water transfers in India:

- Evaluate real and perceived water deficits
- Provide good governance
- Protect water rights
- Consider sound science in the disciplines of hydrology, ecology, and socio-economics
- Ensure sustainability

Figures 6, 7 and 8 illustrate the various mathematical terms of the hydrology of kiwifruit orchards for calculating the green, blue, and grey water footprints from the hydrological perspective.

For a better understanding, a full explanation of all parameters and their symbols in the equations is provided in three separate tables (Tables 16, 17, 18). As an illustrative example, these tables give the values for each of the parameters both for a rainfed (referred to as dryland) and an efficiently irrigated kiwifruit orchard in the Te Puke region.

Hydrological perspective – green water

Green water accounts for the net change of rainwater that infiltrated into the soil ("effective precipitation") over a 1-year time period that is typical for the life-cycle of a kiwifruit product system. The study period for the orchard covers from harvest to harvest (April–April). The net change of green water per ha is normalized by the yield of Class I green kiwifruit for that particular harvest year. It is acknowledged that using average data over a year might ignore some significant in-year effects, but for the purposes of this exploratory study average data were considered appropriate.

As there is sufficient precipitation in winter across New Zealand to replenish the depleted soil water resources in the green water store every year, the system is in balance, and the green water would be expected to be close to zero over the harvest year. In this situation it is believed that it does not matter how much the soil dries out in the summer months because there is ample rainfall in winter to recharge soil moisture. That is, the water content in the soil (soil moisture) of the root zone will be replenished to field capacity every year (see Figure 6). As the drying and rewetting of soils is a natural phenomenon it does not seem useful to consider any impact on the green water resources.

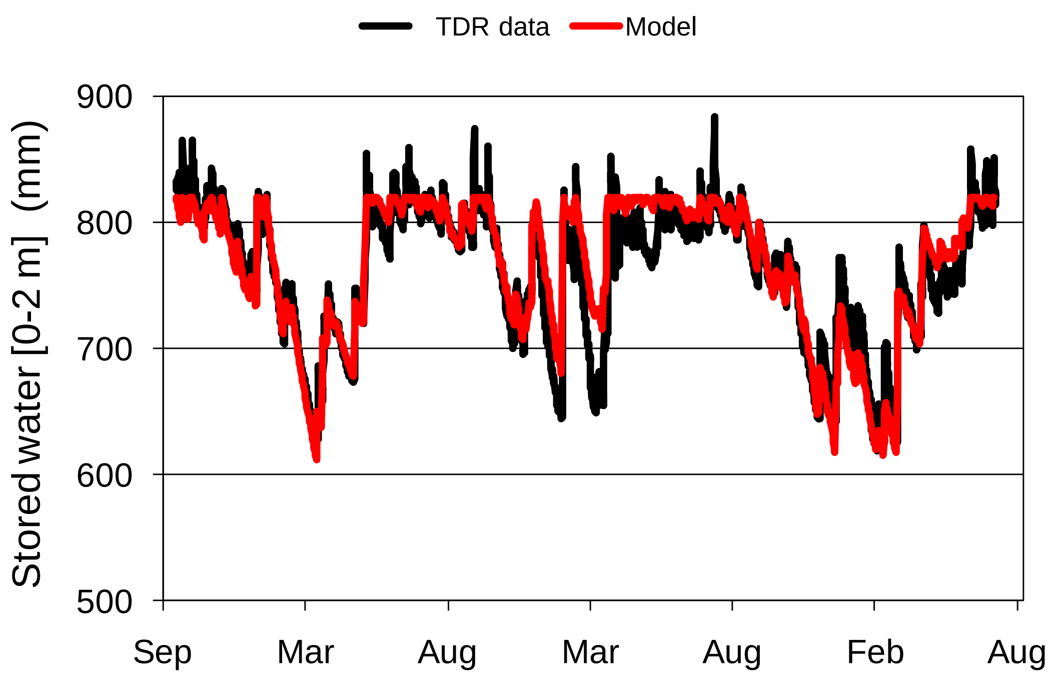


Figure 6 The dynamics of the net change in green water, which equals the water stored in the top 2 m of the soil of a mature kiwifruit vine in the Te Puke area of New Zealand (2005–2007) as measured using Time Domain Reflectometry probes and as modelled using the SPASMO model.

Figures 7 and 8 schematically show the soil–plant–atmosphere system for dryland (non-irrigated) and irrigated orchards, the most important hydrological variables (e.g., evapotranspiration (ET)) and the equations that were used to calculate the green water footprint. Within the hydrological perspective the net change of the green water store is essentially zero. Therefore no environmental impact is considered by the consumptive use of green water by the plants.

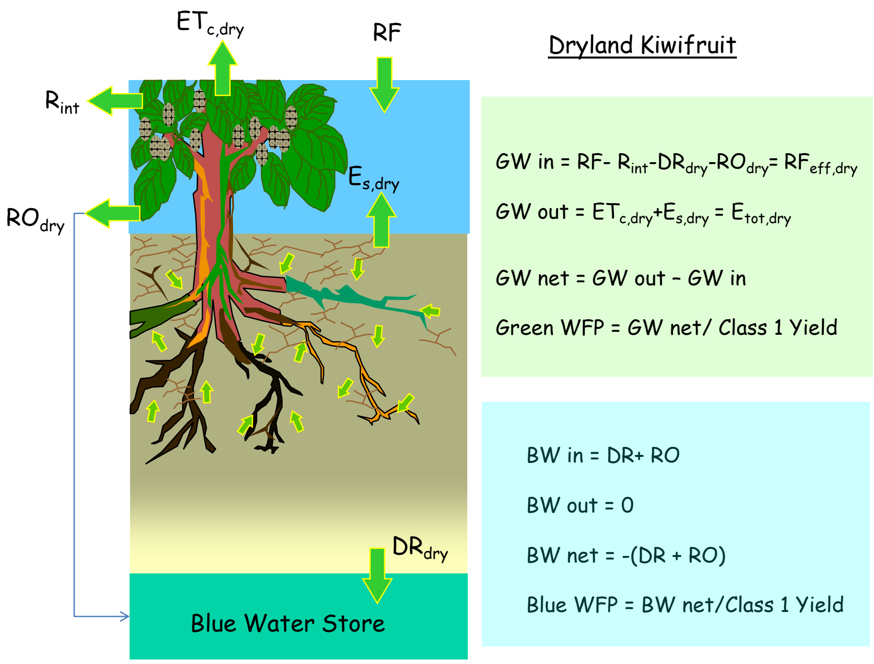


Figure 7 Calculation of the green (Green WFP) and the blue water footprint (Blue WFP) for rainfed (= dryland) kiwifruit using the hydrological perspective. The notation is explained in the text, and in Tables 17 and 18. Note: for simplicity we have omitted here any factors that were necessary for the conversion of different units.

Table 16 Symbols for the calculation of the green water and exemplary values and calculation for a dryland and efficiently irrigated kiwifruit system on soil 1 in Te Puke

Symbol	Unit	Explanation	Te Puke, soil1, dryland	Te Puke, soil 1, eff. irrigated
RF	[mm year]	Rainfall	1492.3	1492.3
R_{int}	[mm year]	Intercepted rainfall	35.6	35.6
DR_{dry}	[mm year]	Drainage out of the rootzone of dryland system	461.2	-
DR	[mm year]	Drainage out of the rootzone of irrigated system	-	526.5
RO_{dry}	[mm year]	Run off from dryland system	102	-
RO	[mm year]	Run off from irrigated system	-	108
$RF_{eff,dry}$	[mm year]	Effective rainfall in the dryland system	894	-
$ET_{c,dry}$	[mm year]	Crop evapotranspiration of kiwifruit in dryland system	673	-

Symbol	Unit	Explanation	Te Puke, soil1, dryland	Te Puke, soil 1, eff. irrigated
$ET_{s,dry}$	[mm year]	Evaporation of soil water and evapotranspiration from grass cover in the dryland system	223	-
$ET_{tot,dry}$	[mm year]	Total evapotranspiration (soil, kiwifruit) in the dryland system	896	-
GW in	[mm year]	Green water input into the soil water store	894	894
GW out	[mm year]	Green water leaving the soil water store	896	896
GW net	[mm year]	Net change of green water in soil water store	2	2
Class 1 Yield	[TE ha]	Yield of class 1 export kiwifruit at the orchard gate	7621	7972
Green WFP	[l/TE]	Green water of one tray equivalent of kiwifruit	2	2

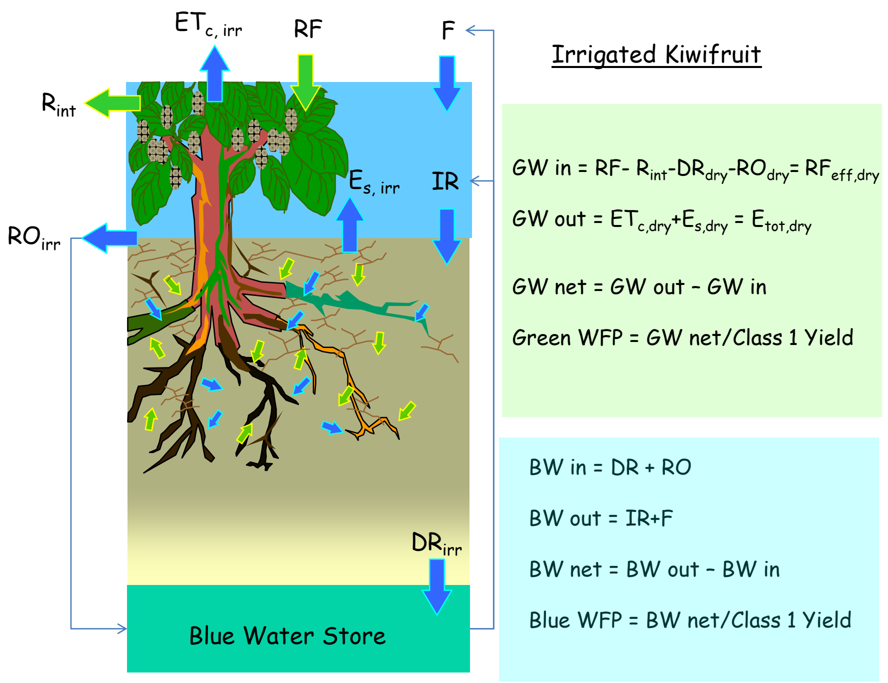


Figure 8 The calculation of the green (Green WFP), and the blue water (Blue WFP) for irrigated kiwifruit. The notation is explained in the text and in Tables 17 and 18. Note: for simplicity we have omitted here factors necessary for the conversion of different units.

Hydrological perspective – blue water

As already highlighted, blue water denotes the freshwater resources of ground- and surface waters (see section 4.1). These resources are scarce, and both a depletion and decline in their quality is a possible risk. In the case of New Zealand kiwifruit production the dominant freshwater resource is groundwater, which is affected by extraction of water for irrigation and contamination by drainage from orchards. The equations for the blue water flows (Figures 7 and 8) quantify a net change in the blue water directly under a kiwifruit orchard system for the period of one year (April–April). The outputs from the blue water store include water extracted for irrigation and frost protection. In this approach drainage and run-off are eventually included as inputs into the blue water system.

In the majority of kiwifruit-growing regions, high rainfall triggers high drainage rates from the areas of kiwifruit production, especially in winter. It is therefore expected that over the period of one year there would be negative values for the blue water values as a result of the larger input of water from run-off and drainage than output from evapotranspiration. In this case ‘negative’ values mark an excess of water, which is assumed to be favourable as this means the groundwater is regularly recharged (the net groundwater recharge) rather than depleted. Depending on local hydrology, it is suggested a specific negative water footprint is needed to maintain, for example, environmentally sustainable levels of river flow. The negative scale is used to enable a future discussion as to where the minimum negative value should be. The net change of blue water per ha is normalized by the yield of Class I green kiwifruit for a particular year.

Table 17 Symbols for the calculation of the blue water (most of them are already given in Table 1) and exemplary values and calculation for a dryland and efficiently irrigated kiwifruit system on soil 1 in Te Puke

Symbol	Unit	Explanation	Te Puke, soil1, dryland	Te Puke, soil 1, eff. irrigated
DR	[mm year]	Drainage out of the rootzone	461.2	526.5
RO	[mm year]	Run off	101.5	107.6
IR	[mm year]	Cumulative amount of irrigation applied	0	116.4
F	[mm year]	Cumulative amount of frost protection applied	0	0
BW in	[mm year]	Blue water input into the blue water resource (groundwater)	563	634
BW out	[mm year]	Blue water leaving the blue water resource (groundwater)	0	116.4
BW net	[mm year]	Net change of blue water in blue water resource (groundwater)	–563	–518
Blue WFP	[l/TE]	Blue water of one tray equivalent of kiwifruit	–738	–649

The blue water values using the hydrological perspective reflect the contribution of a TE (3.6 kg) of kiwifruit on the depletion of freshwater resources. With this method, a positive blue water value in the orchard life cycle stage indicates that no groundwater recharge occurs and depletes the water resources of the underlying aquifer. A negative blue water value in the orchard life cycle stage indicates that the production of kiwifruit is a land use with a groundwater recharge.

The size, and especially the positive or negative nature of the blue water figures in the orchard life cycle stage, not only depend on orchard management but are also strongly influenced by the climate. Without active water management, for example in rainfed kiwifruit orchards, the size of the blue water footprint is driven only by the climate. In a rainfed system this equals the difference between the evapotranspiration (ET) of the soil–plant–atmosphere system and the rainfall (RF). If the difference is negative (ET<RF), there will be a net groundwater recharge, as indicated by a negative blue water value.

On average, all kiwifruit regions grown under rainfed conditions exhibit a net recharge of groundwater supplies, even including the drier regions such as Gisborne, Hawke’s Bay, and

Nelson (Figure 9). While there is on average ample winter rainfall to recharge blue-water resources in all regions based on the hydrological perspective, the blue water also needs to be considered in the context of the summer stress.

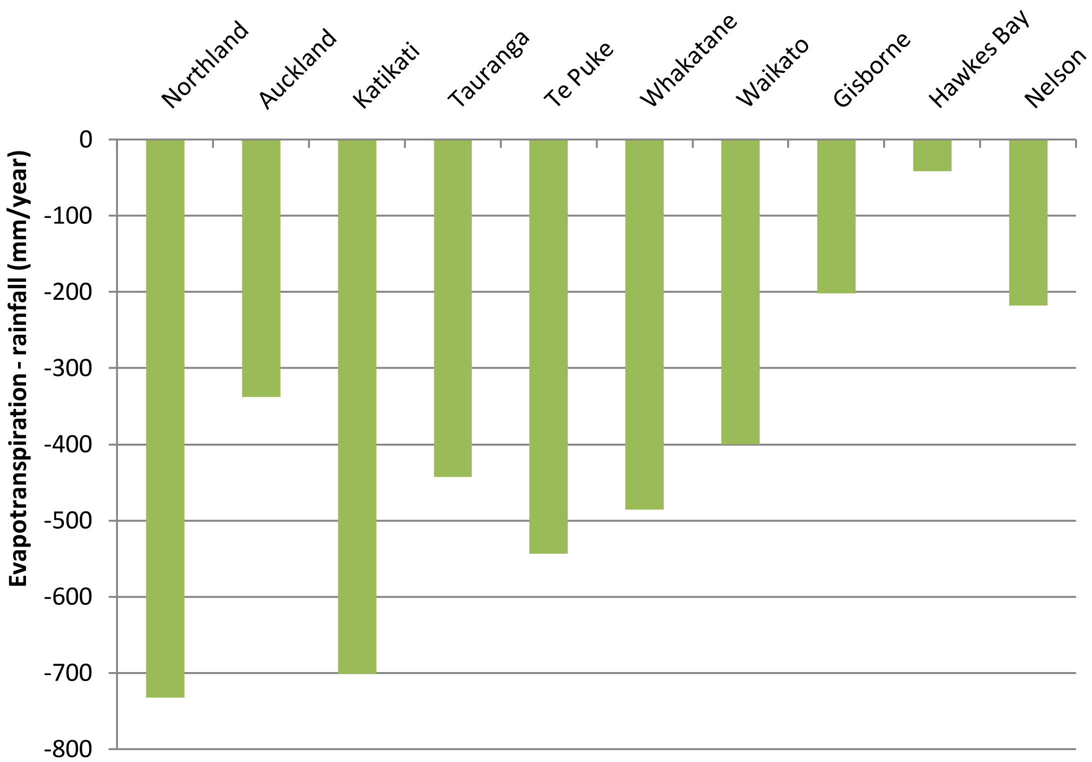


Figure 9 The distribution of the yearly difference between evapotranspiration systems without irrigation and rainfall for the most important kiwifruit growing areas in New Zealand. This difference is the climatic driver of the blue water values. The more negative the difference, the higher the rainfall compared with evapotranspiration and the more negative the blue water value (see Figure 10 and text for more explanation).

Rainfall, varies across the kiwifruit growing regions by more than 20% and is about twice as variable as the evapotranspiration. According to the findings in Figure 9, the kiwifruit growing areas in New Zealand can be separated into three rainfall groups:

- High rainfall areas with an ET-RF < –500 mm/year (Northland, Katikati, Te Puke)
- Intermediate rainfall with an ET-RF between –500 and –250 mm/year (Auckland, Tauranga, Whakatane, Waikato)
- Low rainfall areas with an ET-RF > –250 mm (Hawke’s Bay, Gisborne, Nelson)

The distribution of regional blue water values of kiwifruit (Figure 10) largely reflects the distribution of yearly difference between evapotranspiration and rainfall (Figure 9).

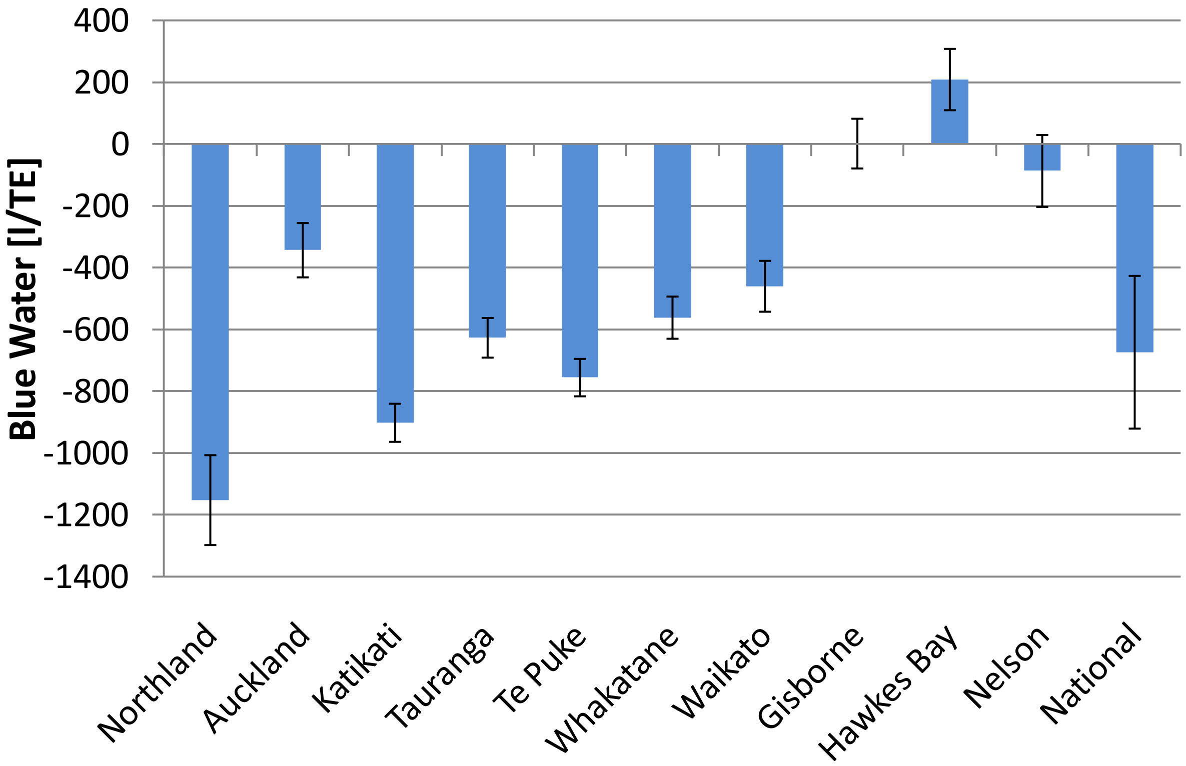


Figure 10 The blue water values of Class I green kiwifruit at the regional and national scale. Note: the bars show one standard deviation due to the variability of 5 regional soils examined during the modelling process within each region.

The high rainfall areas contribute 65% and the areas with intermediate rainfall 27% of the national Class I green kiwifruit production, respectively. Therefore, as the blue water values are smaller in high and intermediate rainfall areas than in the lower rainfall areas of New Zealand, then, based on the hydrological perspective, most kiwifruit production is in areas of net groundwater recharge.

The blue water at the national scale was calculated by weighting the regional blue water values by the regional contribution to the national production of Class I green kiwifruit. Consequently, the national blue water value is negative and reflects this weighting, as shown in Figure 10. The WFN blue water footprint at the national level calculated using the hydrological perspective is –673 l/TE.

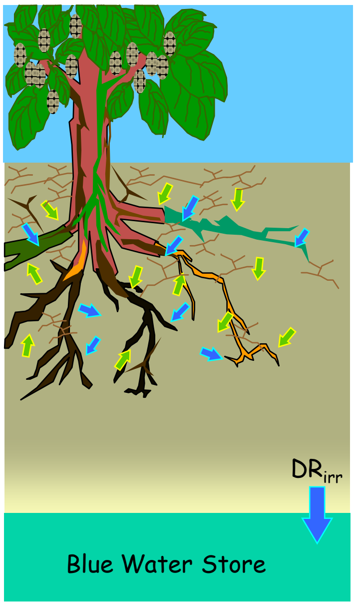
Hydrological perspective – grey water

The grey water quantifies how much water is needed to dilute the load of the chemical with the highest risk of polluting the groundwater when leaving the root zone of kiwifruit. In the hydrological perspective grey water is calculated using the method advocated by the WFN. SPASMO was used to simulate the fate of Terbuthylazine through the root zone. Close et al. (2003) confirmed the accuracy of SPASMO for predicting pesticide fate. Pesticide-fate simulations were carried out by considering the most mobile pesticide in a typical kiwifruit operation in New Zealand. The concentrations of pesticides at 2 m depth, the bottom of the root zone, were always found to be negligible. The herbicide terbuthylazine is expected to be reasonably mobile as it has only a moderate adsorption capacity to soil as is expressed by a small K_{oc} value of K_{oc} = 75 L/kg. An explanation for the Koc value including key references can be found at https://fortress.wa.gov/ecy/clarc/FocusSheets/Physical&ChemicalParameters.htm#koc (last accessed 19 October 2010):

> The K_{oc} value is the soil organic carbon-water partitioning coefficient. It is the ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon per the equilibrium chemical concentration in soil solution. Higher K_{oc} values correlate to less mobile organic chemicals while lower K_{oc} values correlate to more mobile organic chemicals.

Additionally, Terbuthylazin is comparably long lived, with a half-life of $t_{½}$=96 days. Yet, despite these characteristics, the concentrations were found to be negligible. Pesticides were therefore ignored and attention was focussed on nitrate as the grey-water contaminant of concern. In the case of kiwifruit orchards in New Zealand, the pollutant of greatest concern is NO_3-N, and the risks associated with this are eutrophication of streams into which groundwater discharges, and exceedances of drinking-water guidelines for nitrate.

Also considered was the possibility of a pathway of surface runoff and sediment loading to surface water bodies, which would create a grey water footprint as a result of sediment contamination. However, the NIWA (2009) report on Tauranga harbour confirmed that there is an extremely low loading of sediment in the harbour that derives from horticulture.



Dryland Kiwifruit

$GrW = DR_{dry} *(CP-CP_{nat})/(DWS\_CP-CP_{nat})$

Grey WFP = GrW/Class 1 Yield

Irrigated Kiwifruit

$GrW = DR_{irr} *(CP-CP_{nat})/(DWS\_CP-CP_{nat})$

Grey WFP = GrW/Class 1 Yield

Figure 11 The calculation of the grey water footprint (Grey WFP) for irrigated kiwifruit. Note: for simplicity any factors necessary for the conversion of different units have been omitted.

As can be seen from Figure 11, the grey water is calculated as the yearly drainage amount multiplied by a dimensionless concentration-related factor. This term contains the yearly averaged concentration of NO_3-N in the drainage leaving the root zone. The term CP_{nat} of the grey water equation is an opportunity to represent the regionally or nationally specific situation. For example, the natural background concentration for NO_3-N in New Zealand could be selected as 0.0 or 1.3 mg l (see below). In this study, using a precautionary approach, 0.0 m g l was selected.

The drinking water standard was used as the upper admissible threshold concentration; however, other values such as the trigger value for ecological protection, for surface waters, could have been used. In the context of this report the water-quality impact of the leached nitrate concentrations could be measured in relation to five values. For completeness, all five concentrations are listed below:

- 0.0 mg l NO3-N. About 8% of New Zealand's aquifers sampled in 1995–2006 in the New Zealand National Groundwater Monitoring Programme had nitrate concentrations below the detection limit; we assumed this to mean 0.0 mg/l (Anonymous 2007). This term was the 'concentration of pristine groundwater' in New Zealand. This value is used as the natural background concentration as one approach to calculate the grey water footprint in this study.
- 1.3 mg l NO3-N. About 50% of New Zealand's aquifers sampled in 1995–2006 in the New Zealand National Groundwater Monitoring Programme had nitrate concentrations up to 1.3 mg/l (Anonymous 2007). This term was used to describe the average groundwater (GW) concentration in New Zealand and as an alternative value for the natural background concentration as a second approach to calculating the grey water footprint in this study.
- 3.5 mg l NO3-N. An analysis based on the New Zealand National Groundwater Monitoring Programme suggested the value of 3.5 mg/l NO3-N as an "almost certain indicator of human influence" (Daughney & Reeves 2005). This term is an indicator of human influence in groundwater supplies, but not used in this work directly.
- 7.2 mg l NO3-N. The trigger value (TV) for ecosystem protection suggested by the ANZECC guidelines; can be used as the TV for ecosystem protection of groundwater systems. This value was not used directly in the measurement of water the footprint.
- 11.3 mg l. The New Zealand's Ministry of Health's drinking water standard value. In the context of the grey water footprint this is used as the maximum admissible concentration for calculation of the grey water footprint.

The size of the grey water footprint is an indicator of the eutrophication associated with the production of kiwifruit, and represents a measure of the impact of freshwater consumption on the ecosystem. In discussion on the impact of agricultural land use on freshwater resources grey water is often identified as a threshold concentration (e.g., mg l of NO3-N) or a threshold loading rate (e.g., kg NO3-N/ha), NO3-N/ha is considered more appropriate to indicate the risk of eutrophication. The grey water footprint indicates a loading rate, rather than a concentration.

In this study it was assumed that, irrespective of region, approximately 112 kg N-fertilizer are applied per ha and year. The concentrations in all regions are below the drinking water standard of 11.3 mg/l NO3-N. The total grey water footprint for national average orchard is 156 l/TE using the nitrate concentration of 0.0 mg/l.

The regional grey water footprint is established from the size of regional grey water footprints using 0.0 mg/l NO_3-N as the natural background concentration, as shown in Figure 12. Katikati has the highest regional grey water footprint. The leaching of N-fertilser from the soil and the grey water footprint are higher in regions such as Katikati and Te Puke compared, for example, with Hawke's Bay and Gisborne.

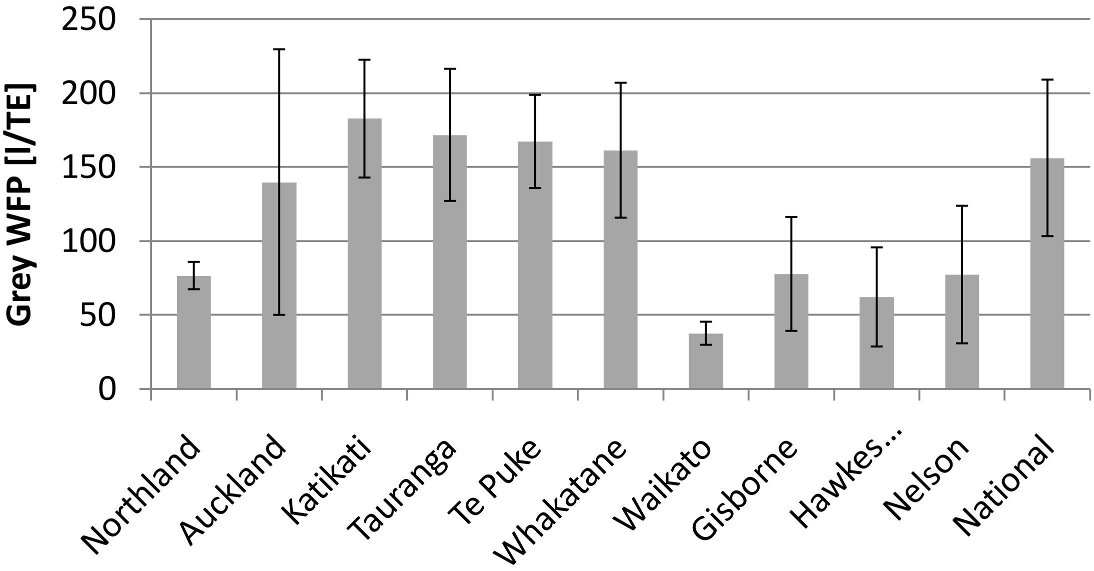


Figure 12 The grey water footprint of Class I green kiwifruit at the regional and national scale. For the calculation we used 0.0 mg l NO3-N as the natural background concentration, and the New Zealand drinking water standard of 11.3 mg l NO3-N as the upper threshold. Note: the bars show one standard deviation due to the variability of 5 regional soils examined during the modelling process within each region.

Indirect freshwater consumption

It was not possible to classify several freshwater inputs recorded in the orchard survey or in the SPASMO modelling as green, blue, or grey during the study. These indirect water inputs are shown in Table 18. These water uses were included in the total WFN water footprint figures calculated in the hydrological perspective but excluded from the WFN water footprint in the consumptive water perspective described in the next section because it was not possible to determine what proportion of the freshwater consumed in each indirect activity was blue, green or grey water.

Table 18 Average non-green, blue and grey water uses for regional orchard activities for an orchard with efficient irrigation and management

Regional average	Electricity (l/TE)[1]	Agchem.(l/TE)	Embodied water (l/TE)	N Fertilizer production (l/TE)
Northland	12.7	3.5	3.0	0.1
Auckland	12.1	3.0	3.0	0.1

Regional average	Electricity (l/TE)[1]	Agchem.(l/TE)	Embodied water (l/TE)	N Fertilizer production (l/TE)
Katikati	5.8	3.0	3.0	0.1
Tauranga	8.4	2.9	3.0	0.1
Te Puke	7.2	2.9	3.0	0.1
Whakatane	9.2	2.8	3.0	0.1
Waikato	7.2	3.2	3.0	0.1
Gisborne	17.2	3.0	3.0	0.1
Hawke's Bay	19.7	3.2	3.0	0.1
Nelson	18.7	3.2	3.0	0.1

Total water values in the hydrological perspective

The total water footprint is defined by the WFN as the sum of the green, blue and grey water. Total water use using 'pristine' water with 0.0 mg NO_3 l yields –460 l/TE, and using the 'natural' background with 1.3 mg l yields –523 l/TE. The impact of eutrophication on the freshwater ecosystem remains, even if there is no depletion of the freshwater resource. A summary of the results is provided in Table 19.

In this instance it appears there is little justification for adding the grey water footprint to the blue water and green water, two freshwater consumption measures to a degradative measure, as suggested in the WFN method. The positive grey water footprint indicates there is a potential risk of eutrophication. However, in the hydrological perspective the grey water is potentially masked in the total water balance by the negative blue water figures and therefore there is little value in aggregating the figures.

Table 19 Total freshwater results by region in the hydrological perspective. For the calculation of the grey water as part of the total of freshwater consumption a figure of 0.0 mg l NO3-N was used as the natural background concentration and the New Zealand drinking water standard of 11.3 mg l NO3-N as the upper threshold

Region (regional average)	Green Water [l/TE]	Blue Water [l/TE]	Grey Water [l/TE]
Northland	–1.8	–1152	76
Auckland	1.7	–343	140

Katikati	2.0	–902	183
Tauranga	3.6	–627	172
Te Puke	3.2	–755	167
Whakatane	2.0	–561	161
Waikato	4.4	–460	37
Gisborne	5.5	2	78
Hawke's Bay	6.6	209	62
Nelson	2.4	–86	77
weighted average national	3.0	–673	156

8.3 Orchard WFN water footprint

The WFN water footprint uses the same SPASMO modelling and orchard data as the hydrological perspective but calculates the WFN blue water footprint in a different way. The key difference between the WFN water footprint and the hydrological perspective is that only evaporative blue water use has been used to define blue water; non-evaporative flows including run-off and drainage are excluded.

WFN water footprint – green water

In the WFN water footprint green water is the total plant evapotranspiration, and if the plant is rain fed the blue water footprint is zero. In other words, green water is the water needed by the plant to grow the kiwifruit without irrigation and excludes rainfall interception and plant run-off, as illustrated in Figure 13.

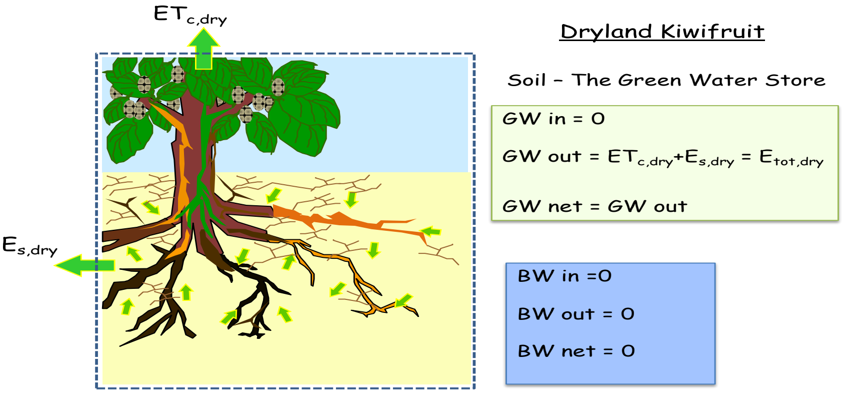


Figure 13 The flows included in the green water footprint. ET = evapotranspiration, subscripts c = crop, s = soil, dry = non-irrigated.

WFN water footprint– blue water

Irrigated crops have a WFN blue water footprint due to the additional water applied to the crop during cultivation. Water flows for establishing the WFN blue water footprint in the consumptive water perspective are illustrated in Figure 14.

The WFN blue water footprint is defined by the incremental evaporation needed for irrigation, including any evaporative water that is lost from the system in order to supply the irrigation water (reticulation losses). Non-evaporative blue water returns to the same catchment are not included in the blue water footprint because this may lead to overestimation. At the time of writing there is little guidance on how to account more accurately for these flows. Excessive irrigation in the orchard leading to run-off or drainage will not be accounted for in the blue water footprint. However, reticulation losses needed for supply water, e.g., at the reservoir or in piping, are accounted for in the blue water footprint.

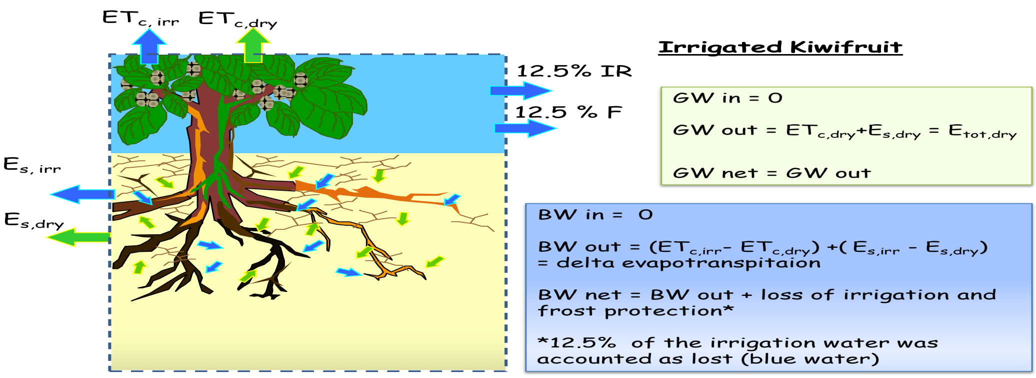


Figure 14 The flows included in the green water footprint. ET stands for evapotranspiration, subscripts ‘c’ refer to crop, ‘s’ soil, ‘dry’ non-irrigated and ‘irr’ irrigated, IR stands for the irrigation input and F for water used for frost protection. Evaporated water accounted for 12.5%.

A number of evaporative blue water losses were difficult to establish in the WFN footprint. For instance, a number of assumptions are needed to establish the evaporative losses from reticulation. In this study the reticulation losses or losses of freshwater from pipes and tanks during its supply were assumed to be a 12.5%, based on work by Milà i Canals et al. (2009). However, it is unlikely that water leaks in underground pipes will evaporate rather than eventually enter a groundwater store. In this study a precautionary approach has been taken, but the assumption on reticulation losses should be treated with caution as a best estimate in the face of a lack of readily available data and further investigation of the issue. It is probable that most irrigation for kiwifruit orchards is taken from groundwater sources so it can be suggested reticulation losses would be much/substantially lower (A. Fenemor, pers. comm., 12 December 2010).

WFN water footprint – grey water

The grey water figures in the WFN water footprint are the same as the grey water quantities established in the hydrological perspective (see section 8.2). A description of the method used to establish results for the WFN grey water in each kiwifruit growing region is provided in 'Hydrological perspective – grey waters' section above. WFN grey water amounts are also summarised in Table 20 below.

WFN regional water footprints

The regional WFN water footprint is given in Figure 15. Each bar is the average WFN Water footprint per region based on the results of the rainfed, over-irrigation, efficient irrigation, and frost protection modelled scenarios. The largest part of the WFN water footprint is formed by green water for all kiwifruit growing regions studied.

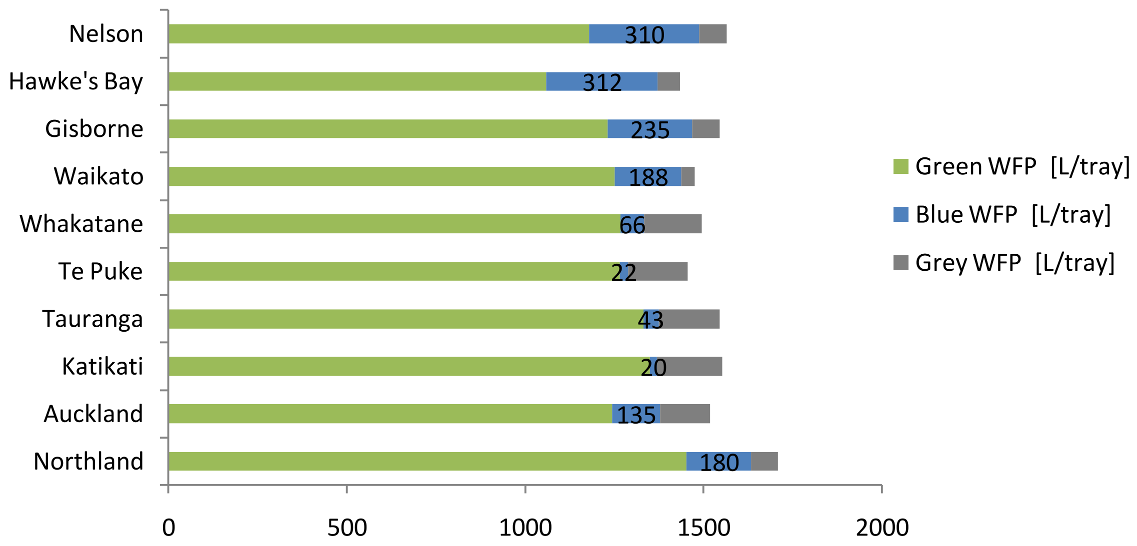


Figure 15 Average WFN Water footprint per region on the rainfed, over-irrigation, efficient irrigation, and frost-protection modelled scenarios using the consumptive water perspective. The numbers on each bar indicate the blue water footprint for each region using the consumptive water perspective.

The WFN blue water footprint for the WFN method in each region is shown in Figure 16. The WFN blue water footprint is largest in the Hawke's Bay and Gisborne regions. The lowest WFN blue water footprint is in the Katikati region, and the Te Puke region, where the majority of green kiwifruit is grown, has the second lowest average WFN blue water footprint.

The different irrigation management scenarios made little difference to the overall water footprint within a region.

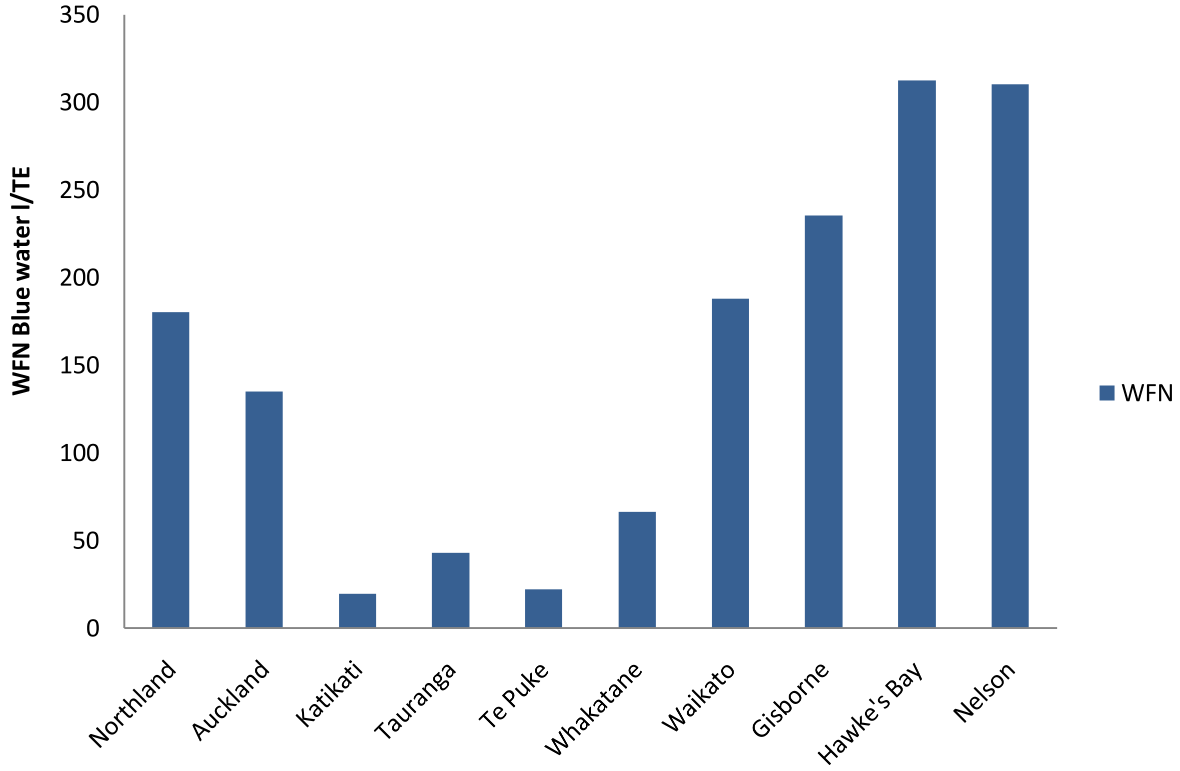


Figure 16 WFN Blue water footprint of tray equivalent of green kiwifruit per region studied.

Total WFN water footprint

A summary of the totals for WFN green, blue water and grey in each region are provided in Table 20. The national average WFN total water footprint in the orchard for Class I green kiwifruit is 1501 l/TE. Eighty-five percent of the weighted national average WFN total water footprint for the orchard is green water, 5% blue water, and 10% grey water. The weighted national average WFN total water footprint for a kg of Class I of green kiwifruit at the orchard is 417 l kg fruit produced. Assuming each kiwifruit weighs 100 g, the WFN total footprint at the orchard based on the weighted national average per kiwifruit is 42 l.

Impact assessment using LCA characterisation factors

FEI is calculated as the ratio of water used versus the total available water in that area (Falkenmark 1986; Raskin et al. 1997; Milà i Canals et al. 2009). WUPR is described below.

Water Use per Resource (WUPR) = Water Used/Water Resources

Table 20 Summary of the water footprints and environmental impact of the Class I green kiwifruit grown per region based on the consumptive water perspective

	Green WFP [l/TE]	Blue WFP [l/TE]	Grey WFP [l/TE]	WUPR	FEI (blue water*WUPR)	WSI	(blue water* WSI)
Northland	1453	180	76	0.006	1.08	0.0102	1.84
Auckland	1243	135	140	0.006	0.81	0.0572	7.73
Katikati	1349	20	183	0.006	0.12	0.0103	0.20
Tauranga	1331	43	172	0.006	0.26	0.0113	0.49
Te Puke	1265	22	167	0.006	0.13	0.0113	0.25
Whakatane	1267	66	161	0.006	0.40	0.0102	0.68
Waikato	1250	188	37	0.006	1.13	0.0106	1.99
Gisborne	1232	235	78	0.006	1.41	0.0102	2.40
Hawke's Bay	1059	312	62	0.006	1.87	0.0103	3.22
Nelson	1178	310	77	0.006	1.86	0.0103	3.20
weighted average national	1283	62	156		3.72		0.98

A high WUPR indicates serious water stress as most available water is being used. Additionally, because of climate variability, the higher the water exploitation ratio, the greater the chances of water shortages during dry years. At the time of writing, WUPR figures provided in the work of Milà i Canals et al. (2009) are only available for the whole of New Zealand and not for individual river basins or catchments.

The use of the WUPR water stress factor in the orchard phase results in a change to the WFN blue water footprint by a factor of 0.006 (0.6%). For example, the WFN blue water footprint for Te Puke is 22 l/TE and the WUPR is 0.13 (22l/TE for Te Puke × 0.006 WUPR). A summary of the total for WUPR impact figures for each region is provided in Table 21, and illustrated below in Figure 17. The weighted national average FEI including all Class I green kiwifruit growing regions for orchard operations is 3.72 as shown in Table 20. Due to the use of only a single WUPR characterisation factor for all regions, the only difference between Figures 16 and 17 is the scale applied; the assessment of environmental impact is shown in the latter figure. The general pattern of the regional results therefore remains unchanged with characterisation using WUPR.

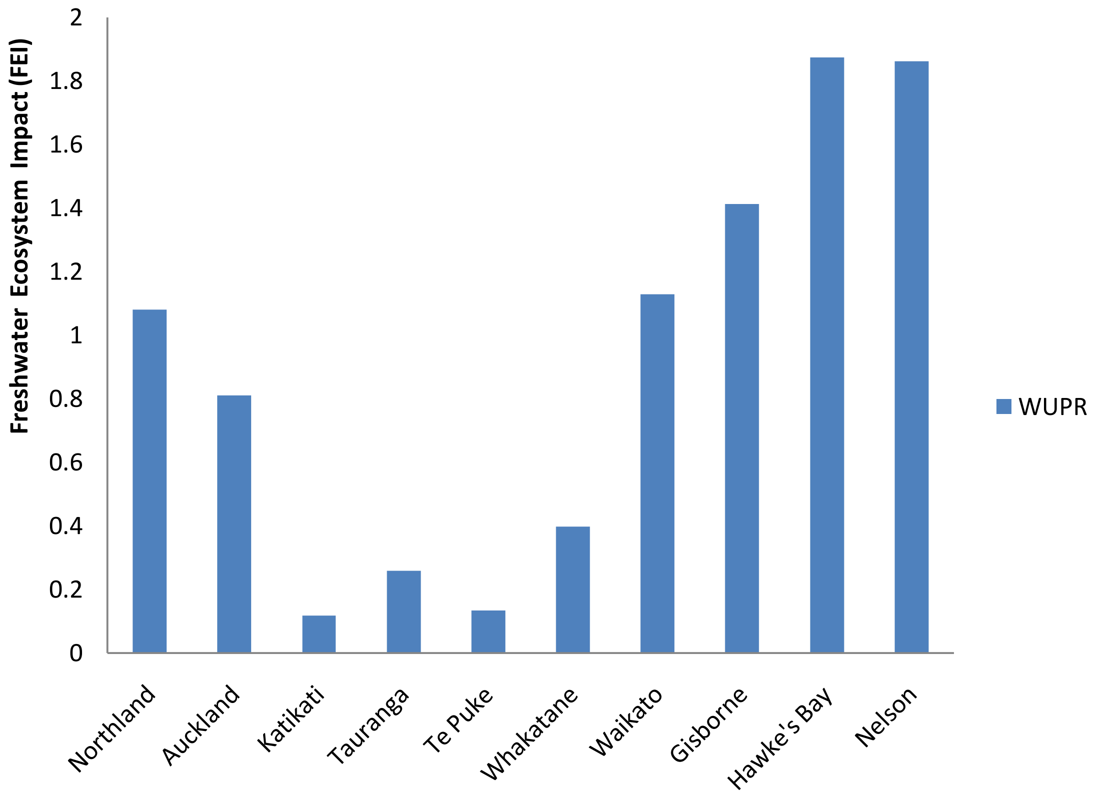


Figure 17.Freshwater Ecosystem Impact (FEI) assessment of freshwater consumption in the different kiwifruit cultivation regions using the WUPR characterisation factor

Comparison of regional impacts

Each region examined in this study contributes to the total Class I green kiwifruit yield in New Zealand. In order to understand which regions contribute most to the environmental impacts of freshwater consumption the results from the consumptive water-based perspective were reanalysed. The relative contributions to the blue water footprint are the same for both WFN and WUPR methods as the WUPR only takes into account a national average characterisation factor. In both cases the impact is dependent on the quantity of water consumed for kiwifruit orchard operations in each region. A summary of the results from the WFN and the environmental impacts of freshwater consumption described by the FEI and regional WSI assessments are provided in Table 21.

An alternative view of the environmental impacts of freshwater consumption is provided by the use of the regional WSI. The regional impact is described as the evaporative blue water use per TE × WSI of the producing region. The WSI described by Pfister et al. (2009) is based on the WaterGAP 2 global hydrological and global water use models, with modifications to account for monthly and annual variability of precipitation and corrections to account for watersheds with strongly regulated flows. The index follows a logistic function ranging from 0.01 to 1. The WSI has a spatial resolution of 0.5 degrees, which is more relevant to describing water stress at a local watershed level than indicators that are based on national or per capita statistics. Especially for large, heterogeneous countries like Australia, China, India, and the US, national statistics provide little insight into local water scarcity

(Alcamo et al. 2003). The results of the WSI characterisation of freshwater consumption impacts within the kiwifruit growing regions are shown in Figure 18.

Unlike the use of the WUPR characterisation factor in establishing FEI, the use of a regional WSI affects the pattern of regional results when compared with the WFN blue water regional footprint results in the consumptive water perspective.

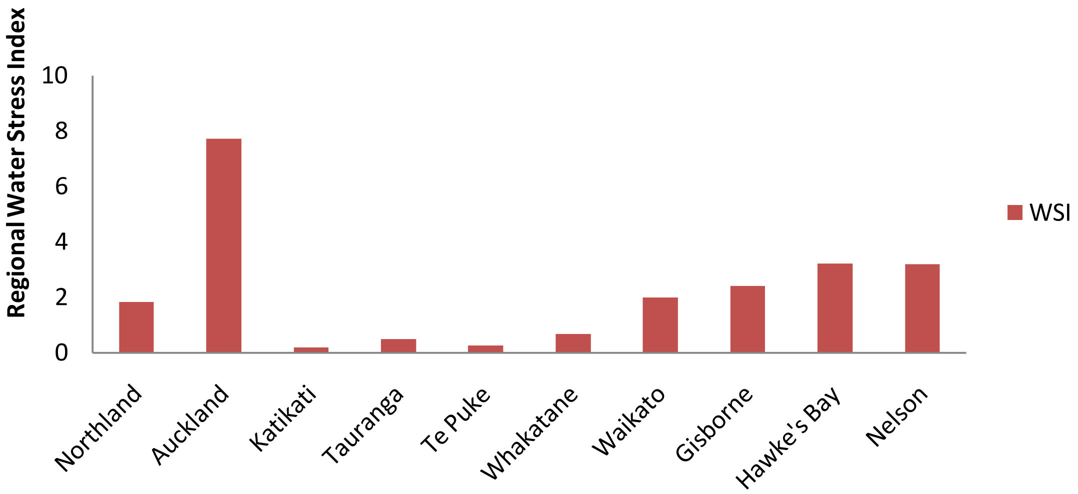


Figure 18 Impact assessment of freshwater consumption in the different kiwifruit cultivation regions using the WSI.

In Figure 19 the relative blue water contribution of each region is shown for the WFN blue water footprint; the same analysis using the WSI for each region is shown in Figure 20. Figures 19 and 20 together show that regions with a relatively small contribution to the national yield can make a relatively large contribution to the environmental impacts of freshwater consumption through higher water stress in a particular region. For example, the contribution of the Auckland region to environmental impacts of freshwater consumption is higher using the WSI indicator than the WFN method, using the consumptive water-based perspective. It is difficult to pinpoint the exact reason for these higher environmental impacts at the orchard in the Auckland region. One possible explanation could be that areas with a high population density tend to place higher stress on water resources because of higher urban use rates and can fare worse than other areas in the WSI, given that the model takes into account basic socio-economic factors that lead to domestic, industrial and agricultural water use, and also incorporates physical and climate factors that lead to runoff and groundwater recharge. The WSI method can also account for reduced variability in areas where water flows are strongly regulated.

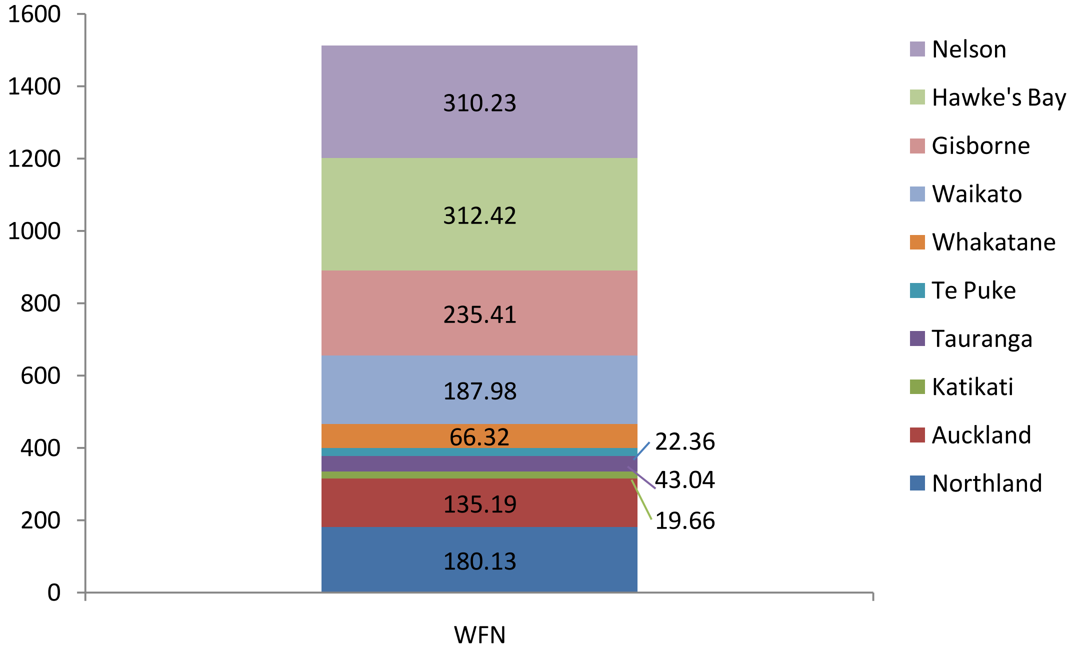


Figure 19 Regional breakdown of WFN blue water of kiwifruit New Zealand (l/TE) using the consumptive water-based perspective.

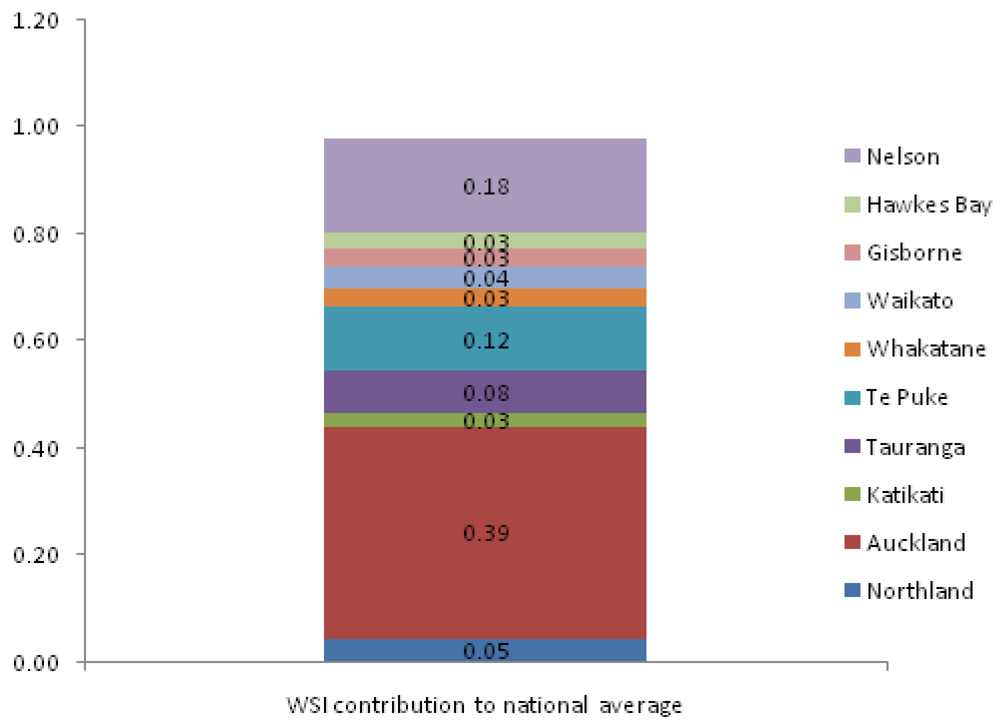


Figure 20 Regional breakdown of WSI indicators for kiwifruit New Zealand (l/TE) using the consumptive water-based perspective.

Indirect freshwater consumption – consumptive water perspective

As already mentioned, it was not possible to determine whether freshwater consumption of certain items including electricity for irrigation was green, blue, or grey water. It was therefore not possible to calculate directly from the orchard survey or later modelling the WFN blue water footprint of different activities, including electricity use in irrigation, agchem production, and frost protection. Unlike the hydrological perspective, the additional indirect freshwater was not added to the overall water footprint because it was not possible to establish the evaporative blue water loss from the additional water consumption.

Perhaps the most important indirect freshwater consumption is for electricity, given that approximately 90% of the electricity used on the orchard is for irrigation (A. Barber, pers. comm., 22 July 2010). In the Mithraratne et al. (2010), electricity use for irrigation was established as 0.023 kWh TE. Based on this data blue water loss can be estimated as 0.55 l/TE using an assumed 15% evaporative blue water loss based on Milà i Canals et al. (2010) as described below:

0.023 × 158.76 = 3.65 l/TE (total water abstracted for electricity use in irrigation)

3.65 × 0.15 = 0.55 l/TE (evaporative blue water loss from electricity use in irrigation)

The total water abstracted in litres per kWh for the average New Zealand electricity mix is derived from research completed at SCION research (J McDevitt pers. comm., 1 June 2010).

This result would imply that the importance of electricity use for irrigation to the overall WFN water footprint is limited. For example, the WFN blue water footprint in the consumptive water perspective for TE Puke is 22 l/TE, and the inclusion of the WFN blue water footprint for the use of electricity in irrigation will represent an increase of 2.5% to the total WFN blue water footprint. However, further research is required to confirm this result. It must also be noted that the use of the electricity figure from the carbon footprinting project relates to the 2007/2008 harvest and might not be representative of electricity use for irrigation over time.

8.4 Summary of orchard results

The different methods for calculating freshwater in both the hydrological and the WFN water footprint clearly result in differences in the green and blue water footprints.

Where run-off and drainage are included in the hydrological perspective, total freshwater use at the orchard is rarely positive for New Zealand kiwifruit growing regions. For example, only the Hawke’s Bay and Gisborne regions have positive totals for freshwater use and blue water use. Weighted results that account for production in each region show the total freshwater use and blue water use are both negative, reflecting a net groundwater recharge at the orchard life cycle stage. For example, the national weighted average for blue water use is –673 l/TE.

The WFN results where run-off and drainage are excluded differ greatly from those in the hydrological perspective. Given that all kiwifruit growing regions have a positive water footprint, the kiwifruit grown in each region consume freshwater in the orchard life cycle stage. The WFN results show green kiwifruit grown in the Nelson, Hawke’s Bay, and Gisborne regions have the highest orchard water footprint from the consumptive water perspective. The weighted national average consumptive water footprint for green kiwifruit is 1501 l/TE.

Impact assessment of orchard freshwater consumption

The WFN blue water results were used as the foundation for LCA environmental impact assessment. The impact assessment of the blue water footprint at the national level using a national characterisation factor does not change the pattern of regional results but could be useful for comparison of the water footprint between green kiwifruit orchards in different nations. Characterisation of evaporative blue water losses using the regional WSI alters the pattern of regional results, for example, the Auckland region has the greatest environmental impact, followed by the Nelson region. The WSI results show examination of regional environmental impacts can be useful for planning of potential expansion of kiwifruit cultivation in different parts of New Zealand. For example, expansion in the Auckland area could potentially have a disproportionately large influence on environmental impacts relative to expansion in other parts of New Zealand.

8.5 Transport of kiwifruit to the packhouse

According to Hoekstra et al. (2009) in the WFN water footing manual 'transport does not consume a significant amount of freshwater'. The WFN manual recommends the exclusion of transport activity from the water footprint, except when biofuel, is used because biomass tends to have a large water footprint as a result of crop cultivation (Hoekstra et al. 2009). It is unlikely vehicles transporting kiwifruit in New Zealand will use biofuel rather than diesel. In this study the water footprint of transport of kiwifruit between the orchard and packhouse has therefore been excluded. However, this is an assumption that should be revisited in future work in water footprinting the kiwifruit supply chain.

8.6 Packhouse/coolstore operations

The WFN water footprint for the packhouse and coolstore was calculated from the data gathered during the packhouse and coolstore survey. The total WFN water footprint for the packhouse and coolstore life cycle stage is 105.5 l/TE. It was not possible to distinguish between the individual green, blue, and grey water use at the packhouse life cycle stage. Therefore all figures quoted for the WFN water footprint represent the total WFN footprint for a particular operation.

The WFN water footprint for packhouse operation is 26.2 l/TE. Of the WFN water footprint for the packhouse, 18.2 l/TE are consumed in direct water, fuel, and electricity use, as shown in Table 21. Materials such as the cardboard used in packing the green kiwifruit contribute 7.99 l/TE of the packhouse WFN water footprint, as shown in Table 22. Coolstore operations produce the largest WFN water footprint in this life cycle stage being 79.2 l/TE. In this life cycle stage most of the WFN water footprint is attributable to electricity use in the packhouse and the coolstore.

Table 21 WFN water footprint for direct water, fuel and electricity use in packhouse operations

	PHC1	PHC2	PHC3	Average (Standard deviation) per TE of Class I kiwifruit delivered
WFN water footprint from direct water use[1]	9.9	5.1	Unknown	0.003 l/TE
WFN water footprint from fuel use[2]	446 673	47 300	216 338	0.07 l/TE (0.07)
WFN water footprint from electricity use[2] (m^3)	47 132	57 689	110 107	18.2 l/TE (1.65)

[1] A 5% evaporative loss was assumed for direct water use based on Milà i Canals et al. (2010).

[2] The WFN water footprints for the different fuels and electricity are given in Appendix 3 Table A4.2.

WFN water footprint of packing materials

The packing material for a TE of green kiwifruit has a total WFN water footprint of 7.99 l. The WFN water footprint of the material components for a TE was established based on the amounts of each packing material used for a kiwifruit tray equivalent. Table 22 provides details of the quantity of materials used for a TE of Class I green kiwifruit and the total WFN water footprint for each material used.

Primary data for freshwater consumption of packaging materials were not available. In this study the WFN water footprint for materials used in packing of kiwifruit has been established from the energy used for the production of the materials in the packaging. Energy use figures were taken mostly from the Australian Life Inventory data (Grant et al. 1998, 1999) and WFN figures from the water footprint data of different fuel and energy types in Gerbens-Leenes et al. (2008). A detailed description of how the water footprint for different materials was calculated is given in Appendix 4. For a detailed estimate of the grey water footprint a survey of the New Zealand facilities producing the cardboard and wood components would have been necessary. A survey focussed on establishing the water footprint of New Zealand packing materials is outside the scope of this study.

During the analysis of materials it was not possible to distinguish between the blue and grey water footprint because data were obtained from secondary sources. Therefore results for the total WFN water footprint partly included the grey water footprint associated with the production of the packing materials (see Appendix 5).

Some packing materials such as polyethylene terephthalate (PET) and polypropylene (PP) have relatively high water total water footprints of 72.6 l kg and 69.3 l kg respectively, when compared with cardboard at 16.4 l kg. However, because of different amounts used in a TE, both PET and PE contribute relatively little to the water footprint of packing materials. Cardboard and wood contribute approximately 93% to the WFN water footprint of packing materials.

Table 22 Average amounts of packing materials and associated water footprints per TE of Class I green kiwifruit

Packing material component	Material amount per TE of Class I green kiwifruit in kg TE. (standard deviation)	WFN water footprint[1] of materials per TE of Class I green kiwifruit in l/TE. (Standard deviation)
Cardboard	0.249 (0.003)	4.08 (0.06)
Wood	0.124 (0.006)	3.37 (0.17)
PP	0.003 (6E-05)	0.20 (0.004)
PET	0.001 (0.0002)	0.10 (0.01)
HDPE	0.011 (0.001)	0.22 (0.02)
Paper	0.0003[2]	0.02[2]
Total WFN water footprint	0.388 (0.01)	7.99 (0.23)

[1] The grey water footprint of the packing materials was only partly considered.

[2] Figures were recorded for two of the three packhouses therefore only mean figures are provided.

Coolstore operations

The total WFN water footprint for different activities at the coolstore is shown in Table 23. Activities at the coolstore contribute 79.2 l/TE to the WFN water footprint in this life cycle stage. Refrigerant leaks were found to account for a very small amount of freshwater consumption during operation of the coolstore.

Table 23 WFN water footprint details of direct water use, fuel use and electricity use from the packhouse/coolstore survey

	PHC1	PHC2	PHC3	Average (Standard deviation) per TE of Class I kiwifruit delivered
WFN water footprint from direct water use[1]	23.9	17.6	Unknown	0.007
WFN water footprint from fuel use[2]	13 844	67 017	581 493	0.07
WFN water footprint from electricity use[2] (m^3)	243 923	230 755	440 426	79.2

[1] A 5% evaporative loss was assumed for direct water use based on Milà i Canals et al. (2010).

[2] The WFN water footprints for the different fuels and electricity are given in Appendix 4 Table A4.2.

As the coolstore operators were not able to estimate the losses of refrigerants for the 2009/10 harvest, we assumed a refrigerant leakage rate, of 0.1486 g TE, as was estimated by Mithraratne et al. (2010). Multiplying 0.1486E-03 kg TE with the estimated water footprint of the refrigerant HFC-22 (8.9 l kg) yields 1.3E-03 l/TE. Therefore, the contribution of refrigerant losses to the WFN water footprint is extremely small. The details of the calculation of the water footprint of refrigerant HFC-22 can be found in Table A4.1 in Appendix 4.

LCA characterisation for packhouse and coolstore

As highlighted above in the discussion of the WFN water footprint, it was not possible to distinguish blue water accurately from grey water use in packhouse and coolstore operations. In turn, it was not possible to calculate an accurate figure for evaporative blue water losses. To provide an assessment for awareness raising and for refinement in the future it was assumed that the WFN water footprint consisted entirely of blue water. Based on this assumption evaporative blue water consumption can be calculated based on electricity figures in Table 12 and Table 14.

The total electricity use per TE in packhouse and coolstore operations is 0.589 kWh TE. The total consumption of water needed to generate the electricity used in packhouse and coolstore operations is 93.51 l/TE or 0.589 × 158.76 l kWh (J McDevitt pers. comm., 1 June 2010). Assuming evaporative blue water consumption represent 15% of total water consumption, based on Milà i Canals et al. (2010), evaporative blue water loss from electricity use in the packhouse/coolstore amounts to 14.03 l/TE.

Evaporative blue water losses within the packhouse and coolstore were converted into environmental impact, using a WUPR of 0.006 for New Zealand results in an FEI of 0.084. A full assessment of the best characterisation factor using the WSI for the water footprint of New Zealand electricity is beyond the scope of this study. In this assessment a WSI of 0.0107 (for the Waikato region of New Zealand) was used, assuming electricity used is generated locally. Using a WSI 0.0107 leads to an impact of 0.150for freshwater consumption in packhouse/coolstore operations.

9 Results - Post-packhouse/coolstore results

Gathering primary data for further life cycle stages beyond the packhouse/coolstore was beyond the scope of the project. Using only secondary data sources, including WFN and LCA publications, it was not possible to obtain the quantity or quality of data needed to accurately calculate the water footprint of green kiwifruit across the entire supply chain. In this section the water footprint at different stages of the life cycle is discussed through a series of examples. Each example is intended to highlight important issues that relate to establishing the water footprint at that particular life cycle stage. In general the approach was to investigate the WFN footprint and then use these data for the LCA environmental impact assessment whenever possible. In most life cycle stages the water footprint figures produced are based mainly on electricity use.

This approach is consistent with the research conducted in the packhouse/coolstore life cycle stage. In most cases water footprint numbers are only provided for illustrative purposes. It is important to understand from the outset, as Hoekstra et al. (2009) point out, that ‘in most cases the contribution of the factor energy will be a small percentage of the overall water footprint of a product’ (p. 13). Therefore the research in the latter stages could potentially underestimate the water footprint in the later life cycle stages. Further research is therefore needed to provide a comprehensive water footprint of all life cycle stages for green kiwifruit supply chain using either the WFN or LCA method.

9.1 Departure port operations

Hoekstra et al. (2009) state ‘transport does not consume a significant amount of freshwater except when vehicles are run on biofuel’ (p. 13). As already mentioned above, it is unlikely vehicles transporting kiwifruit in New Zealand will use biofuel rather than diesel. Therefore, in this study the water footprint of transport of kiwifruit between the packhouse and coolstore has been excluded. However, this is an assumption that should be revisited in future studies aiming to understand the water footprint of the kiwifruit supply chain.

Electricity use at the port was estimated as 0.012 kWh TE in Mithraratne et al. (2010). Based on electricity use, the WFN water footprint at the port is 1.91 l/TE. Evaporative blue water losses, based on a WFN water footprint of 1.19 l/TE, are 0.286 l/TE (1.91 × 0.15, assuming a 15% evaporative blue water loss).

Blue water evaporative losses in the departure port operations, based on electricity use, were converted into environmental impact using a WUPR of 0.006 for New Zealand to produce an FEI impact of 0.002. Using a regional WSI of 0.0113 (the WSI for the Tauranga region of New Zealand) leads to a WSI impact of 0.022.

9.2 Shipping between New Zealand and the UK

At the time of writing it not common practice to use biofuels or biofuel mixtures for shipping, although a number of trials have been conducted recently by Maersk Line (Maersk Line 2010). Therefore in this study the water footprint of transport of kiwifruit between New Zealand and Belgium, and Belguim to the UK has been excluded. However, this is an assumption that should be revisited in future work in water footprinting to ensure it remains an accurate reflection of activity within the supply chain.

9.3 Repacking in Europe

No data were available for activities at the destination port or repackaging facility in Belgium (Mithraratne et al. 2010). Also no water footprint data were available for the production of polystyrene to make spifes. Therefore it was not possible to establish the WFN water footprint for the European repacking operations without further investigation.

Electricity use during repacking was examined to provide a measure of potential freshwater consumption. For the purposes of this study it is assumed the machinery used in repacking is technically similar to the machines used in the original packing green kiwifruit. Based on this assumption and the further assumption that repacking occurs in the UK not in continental Europe for ease of illustration, the potential blue water evaporative loss for the electricity use in repacking can be described. Based on Milà i Canals et al. (2010), the blue water evaporative consumptive loss from electricity in the UK is 2.8 kg kWh or 2.8 l kWh (medium voltage). Electricity use measured by the New Zealand packhouse survey in this project is 0.110 kWh TE. Therefore, blue water evaporative loss for electricity use in repacking is 0.31 l/TE.

Evaporative blue water loss based on electricity use in repacking operations was converted into environmental impact, using a WUPR of 0.065 for the UK to produce an FEI of 0.02. A full assessment of the best WSI for the water footprint of UK electricity is beyond the scope of this study. A WSI of 0.0107 (for western Wales) was applied primarily to give a comparison with the energy mix of New Zealand, which is based primarily on hydropower. This area of western Wales is where hydropower dams in the UK are located, but the use of this WSI is purely for illustrative purposes in the absence of a WSI that is representative of the UK electricity grid. Using a WSI 0.0107 leads to an impact of 0.003.

Water consumption during coolstore of green kiwifruit before distribution has been excluded in this calculation because it is assumed kiwifruit are distributed to retailers without coolstore as soon as the fruit is repacked. Direct water use and the water footprint of materials are also excluded from this limited evaluation. These elements of the water footprint need appropriate investigation in the future to establish an accurate water footprint of repacking activity in Europe.

9.4 UK Transport

The discussion in this section is used to highlight issues related to transport when vehicles use biofuels. The work presented here is a preliminary investigation to stimulate discussion of water footprinting issues for transport and for when biofuels are used in transport. A full water footprint for retail distribution and consumer transport would require further investigation.

As stated above WFN recommends the inclusion of biofuel based transport in a water footprint (Hoekstra et al. 2009). Here the biofuel use by a consumer passenger car used to pick up groceries from a local retailer is examined.

Since April 2008 petrol and diesel used in passenger cars in the UK have had to incorporate a specified percentage of biofuel to meet the Renewable Transport Fuel Obligation (RTFO). The current UK legislation sets a target of 3.25% biofuel by volume for both petrol and diesel for 2009/2010 (Renewable Fuels Agency 2010). In this study it is assumed all biofuels used for car use in the UK are sourced from the UK. Further research is needed to establish the proportion of UK biofuels sourced from non UK sources.

Assuming the consumer travels 5.5 km each way (carrying 11 kg of shopping) by car between a local supermarket and home results in an average distance of 1 km of travel per kg of groceries purchased (Mithraratne et al. 2010). A travel distance of 3.65 km is therefore required in order to purchase a 3.65 kg tray equivalent of kiwifruit.

To investigate the water footprint of transport it is necessary to know vehicle fuel efficiency. Based on information from the ecoinvent database, vehicle efficiency was estimated to be approximately 13 km l (0.0769 l km). In this scenario biofuel required would be 0.0025 l km (0.0769 × 0.0325) and 0.009 l (0.0025 × 3.65) for a TE of green kiwifruit.

From a recent study of the WFN water footprint of sweeteners and bioethanol by Gerbens-Leenes and Hoekstra (2009) it is possible to estimate that approximately 250 l of blue water are consumed to make a litre of biofuel in the UK. Using the 250-l estimate the blue water consumption of biofuel in a passenger car collecting groceries is 2.25 l (250 × 0.009). Therefore, the WFN blue water footprint is represented by 2.25 l/TE. The total WFN water footprint is estimated to be 5.4 l/TE (600 × 0.009) based on the total WFN green, blue and grey footprints shown in Leenes and Hoekstra (2009).

It is not clear from Gerbens-Leenes and Hoekstra (2009) whether the figures quoted in this report are for total WFN blue water consumption or just evaporative losses that are needed in the Milà i Canals et al. (2009) method, so caution should be exercised when using the data calculated above. Applying the UK WUPR of 0.065 to convert the blue water consumption in biofuel into an environmental impact, results in an FEI 0.15. To assess the environmental impact using WSI, the location of the biofuel crop cultivation is needed. As an example, the WSI listed for Cambridgeshire and Lincolnshire (WSI 0.1481) was used to describe the regional environmental impact, resulting in a regional impact of 0.33.

Vehicle efficiencies differ widely both for passenger cars and commercial vehicles. Preliminary investigations into the biofuel use in commercial vehicles highlighted that a similar set of issues as above would be raised in establishing the water footprint of distribution of fruit within the UK. Fuel efficiency is related to several variables such as dimensions, weight, loading, engine power; even driving style can be important. Using additional data from a recent report published by the Logistics Research Centre at Herriot Watt University it possible to estimate the water footprint of biofuel used in the distribution of green kiwifruit in the UK. It was estimated that in 2008 the average articulated lorry in the UK had a fuel efficiency of 7.6 mpg (or 2.7 km per litre) for vehicles with a gross weight over.32 t. The report also provides useful data on the average payload (15.2 t) and states that in 2008 articulated lorries ran on average 4 km empty for every 10 km that they ran loaded.

Based on information in McKinnon (2010) and the data listed above for establishing the water footprint, the biofuel required is 2.957 l and the blue water footprint of distribution by heavy goods vehicles is 0.18 l/TE[3].

Applying the UK WUPR to blue water consumption in biofuel during distribution by heavy goods vehicles results in an FEI of 0.01. Appling the WSI listed for Cambridgeshire and Lincolnshire (WSI 0.1481) to describe the regional environmental impact results in a regional impact of 0.03.

As detailed in Table 15 (section 7.4), both light and heavy goods vehicles are used for distribution of fruit by UK retailers. Information on the fuel efficiency of light goods vehicles (vans) is more difficult to find in secondary sources than for heavy goods vehicles. McKinnon (2007) suggests that fuel efficiency is 12 km l (0.08 l km) for vans, and in this case the blue water footprint of distribution by vans can be estimated to be 0.28 l/TE[4]. However, an alternative value for the fuel efficiency of vans, 0.20 l km, can be used from the ecoinvent database. Using the ecoinvent data, the blue water footprint is estimated to be 0.66 l/TE. Neither estimate of the blue water footprint of distribution of green kiwifruit is likely to be significant in terms of the overall water footprint of the supply chain.

Applying the UK WUPR to convert the blue water consumption in biofuel during distribution by vans (based on the ecoinvent data to provide a precautionary approach) into an environmental impact results in an FEI of 0.04. Appling the WSI to describe the regional environmental impact results in a regional impact of 0.10.

9.5 UK retailer

The carbon footprint of the kiwifruit supply includes two inputs at the retailer stage of the life cycle. Both heat and electricity use are included in the carbon research based on Nielsen et al.'s (2003) estimates for potatoes sold at retailers. No data were available for energy generated from heat in the literature.

In this study, for illustrative purposes the total energy requirement for storage of kiwifruit at the retailer was considered to be supplied by electricity from the UK grid. The total energy requirement is 0.07 MJ per TE or 0.252 kWh. Based on Milà i Canals et al. (2009) the blue water evaporative consumptive loss from electricity in the UK is 2.8 kg kWh or 2.8 l kWh (medium voltage) and blue water evaporative loss at the retailer is 0.71 l/TE.

Evaporative blue water loss based on electricity use at the retailer operations was converted into environmental impact, using a WUPR of 0.065 to produce an FEI impact 0.05. Using a

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[3] ((1/2.7)×0.0325×246.4×250)/(15200/3.65) = 0.18 l/TE where average fuel efficiency is 2.7 l/km, 3.25 (0.0325) is the percentage of biofuel content per litre of fuel, 246.4 km is the average transport distance once empty running is factored in, 250 l is the freshwater consumed per litre of biofuel used, 15 200 kg is the average payload, and 3.56 kg is the weight of a TE of green kiwifruit.

[4] Average payload is assumed to 1.75 t (50% loading for a 3.5 tonne van); return journey is assumed to be empty running.

WSI 0.0107 (the WSI for the western Wales region of the UK) for consistency with other life cycle stages results in a impact of 0.01.

9.6 UK household consumption

The consumption of water at different households in the UK is likely to have differing environmental impacts. For example, water used in toilet flushing in two similar households located in different parts of the UK could have different impacts depending on whether the use of water was in a low or high stress area. Milà i Canals et al. (2010) also suggest that household consumption of water can be significant, contributing up to 44% of the system studied in their recent research on broccoli.

Mithraratne et al. (2010) does include data related to electricity use in hand drying of 0.023 kWh, based on the consumption of broccoli (Milà i Canals 2007). Using these data as a guide, the blue water evaporative loss from hand drying is 0.06 l/TE. Blue water evaporative loss from electricity use results in FEI 0.004. Using a WSI 0.0107 (for western Wales) results in a 0.006 regional environmental impact.

However, it is difficult to see how electricity use alone is an appropriate measure of the water footprint in the household consumption stage, given the creation of wastewater at this stage. Data in Munoz et al. (2008) calculated 25 l of wastewater were associated with consumption of 985 g of broccoli. The wastewater includes used tap water from flushing the toilet, hand washing, and washing towels. For this study, kiwifruit were assumed to have the same wastewater values as broccoli (per kg). Tap water used in the household would be considered blue water in both WFN and LCA methods. For each TE consumed, 92.64 l of wastewater is produced. In Milà i Canals et al. (2010) a 12.5% loss has been used to describe the blue water evaporative loss from tap water use. However, it is also noted that distribution losses within the urban networks supplying water to households are usually higher than 12.5%. Average losses in UK urban networks are about 22%, although the main part of those losses is non-evaporative, because leaks mostly occur underground. In the absence of more complete data, blue water evaporative loss is estimated to be 12.5% as the best estimate. For awareness-raising reasons this study also assumes 12.5% blue water evaporative loss from direct water use in the household.

Based on the generation of 92.64 l wastewater, the evaporative blue water loss would be 13.90 l. Added to the evaporative loss for electricity use in the home, total blue water evaporative loss is 13.91 l/TE. Blue water evaporative loss through household water use results in FEI 0.96. The environmental impact illustrated by use of the WSI can vary between different locations depending on where green kiwifruit are consumed. For instance, the WSI for Skelton in Scotland is 0.01 and results in an environmental impact 0.14; use of a WSI for London of 0.9956 results in a regional environmental impact from the WSI of 13.85.

In the work of Ercin et al. (2009) the research suggests consideration of grey water should be omitted from a WFN water footprint if wastewater is treated before discharge to the environment. In the UK, almost the entire population is connected to a wastewater treatment plant (Eurostat, 2003). In this study grey water generation from households in the UK is assumed to be zero and is excluded from further consideration.

10 Implications and findings

This research has attempted to establish an indicative sector water footprint for the green kiwifruit supply chain using the WFN water footprinting method and some of the latest LCA environmental impact assessment methods. In completing the project it was found that it is important to think about specific issues within the context of the water footprinting methods applied. The specific demands of the water footprinting methods mean that data and methods applied in the previous carbon footprinting work (Mithraratne et al. (2010) are of limited value.

The research has identified a number of important data gaps and methodology interpretation issues for further consideration during the completion of primary sector water footprinting exercises. For example, inventories of freshwater consumption are rarely completed on a consistent basis at the moment. The latest version of ecoinvent (V2.2) is one of the most comprehensive databases for life cycle inventories but rarely includes data for water abstraction. Current LCA databases do not capture details of freshwater consumption. If freshwater abstraction is recorded in the database then the basis of collection and the quality of data are usually difficult to establish. At the time this research was completed there were few useful secondary literature sources for data on freshwater in the relevant areas. This lack of readily available data hampered the ability of the research to accurately understand and establish the WFN and LCA based water footprint of green kiwifruit across the supply chain. However, it is reasonable to suggest the list of case studies and data sources is growing rapidly and sufficient data might become available in the future.

Perhaps most importantly, this study has identified a number of hotspots that can be used for reducing the water footprint of green kiwifruit. In the following pages the implications and findings of the research are split into relevant life cycle stages with a grouping for the stages beyond the packhouse and coolstore stage.

Important issues for the calculation of the water footprint across the supply chain have been highlighted with relevant examples whenever possible. It is also important to note the results for the orchard form the foundation for further water footprinting work and potentially a comparison of the cultivation of green kiwifruit in New Zealand and in other countries, e.g., Italy.

10.1 Orchard findings and implications

The analysis of the orchard life cycle stage formed the backbone of the completed research; given this stage was the part of the supply chain from which the most comprehensive results were obtained using both the WFN and LCA methods. Data from the orchard survey were supplemented by data provided by SPASMO modelling. The orchard survey targeted a small sample of orchards that could provide the level of detail required on rainfall, soil moisture, and irrigation inputs. Without this level of detail it would have been extremely difficult to determine water inputs for the study. It is worth noting it is unlikely the majority of kiwifruit orchards would be able to provide the level of detail required for water footprinting without significant external guidance. The SPASMO model, which complemented the orchard survey by providing essential data on water use during growth, also helped provide a level of detail that could potentially simulate freshwater consumption on a typical orchard for use in the future.

During the project an alternative perspective was used for calculating blue water use due to difficulties interpreting the WFN water footprint manual. It is important to stress that the hydrological perspective and WFN water footprint results both represent a genuine attempt to use the expertise within the team of scientific hydrological rigour and LCA product footprinting to interpret the wording of the WFN guidelines.

In the absence of a definitive equation within the manual to describe the WFN blue water footprint for green kiwifruit it was decided to present the results for both a hydrological perspective, which includes run-off and drainage as part of blue water, and a consumptive-water in the WFN water footprint, which omits these elements from the calculation of blue water and is based on evaporative blue water losses.

Orchard hydrological perspective

Using the hydrological approach provides an important and alternative perspective on the freshwater use at the orchard life cycle stage. Results from the hydrological perspective show that when run-off and drainage (as described in section 8.2) are included in the WFN water footprint it is possible to derive a negative value for a water footprint. A negative value for a water footprint means there is a net groundwater recharge rather than depletion during the cultivation of green kiwifruit. Based on the hydrological perspective, for most kiwifruit-growing areas of New Zealand the green water footprint varies little from year to year and is essentially zero for all the regions examined. This is another major difference between the hydrological perspective and the WFN results. The negative freshwater use results in the hydrological perspective also suggest there is limited scope for reduction activities in the majority of regions growing kiwifruit. This is an issue that is discussed further in the reduction report (Deurer et al. 2010) completed as part of this project.

Unlike WFN green water, WFN blue water volumes using the hydrological perspective vary between the different 10 kiwifruit regions researched. All green kiwifruit cultivation regions, apart from Gisborne and Hawke's Bay, display a negative blue water footprint. For example, the blue water footprint for green kiwifruit in the Te Puke region is –783 rainfed orchards and –710 in efficiently irrigated orchards. However, in Gisborne and Hawke's Bay the WFN blue water footprint using the hydrological perspective is as a regional average 2 l and 209 l, respectively. The average national blue water footprint using the hydrological perspective is –673 l/TE.

Grey water describes the volume of water needed to dilute contaminated water to a safe or pristine level. In the case of green kiwifruit orchards the substance of most concern is NO_3-N and the risk associated with this is eutrophication resulting from nitrogen run-off. The grey water footprint is highest in the Katikati region at 183 l/TE. The pristine water level represents a cautious approach to determining the grey water footprint and effectively ensures the worst case scenario is used.

The addition of grey water to green and blue water results in a negative total water footprint for the majority of kiwifruit regions. For example, the total water footprints for the Katikati and Te Puke regions are –695 l/TE and –560 l/TE, respectively.

The focus on hydrological vigour can be seen as an effort to address one of the major criticisms of the current WFN method. The calculation of the values in the hydrological perspective has been derived using a method that is recognisable to the hydrologist as following the principles of water balance. Other major criticisms of the WFN method include that the water footprint produced is not yet equivalent to an environmental impact, in the same way a carbon footprint is. Chapter 4 of the water footprinting manual does outline guidance for a sustainability assessment that can be used to assess the environmental impacts of freshwater consumption but it is not designed to produce a single number indicator in the same way as a LCA. Rather, the sustainability assessment is geared more to water resource management. In most cases the assessment of environmental impacts is omitted from water footprinting studies (Pfister, 2009).

The results produced in this project using the hydrological perspective give an insight to the regional environmental impact through the groundwater recharge level and extend a typical WFN footprint beyond simply the presentation of the volume of water consumed. For example, the positive blue water footprint for Gisborne and Hawke's Bay could potentially mean these are regions higher environmental impact.

However, what constitutes an acceptable blue water footprint for a specific location is an issue for further debate. Every aquifer depends for good management on a minimum amount of recharge via drainage so an appropriate hydrological measure should focus on the depletion of groundwater beyond an optimum amount of drainage recharge, e.g., mean annual flow (A. Fenemor, pers. comm., 10 December 2010). With further development, the hydrological perspective could potentially be useful for identifying what level of recharge is needed and what water footprint figures are desirable for appropriate water resource management. The introduction of an optimal blue water footprint adds a layer of complexity and could increase the difficulty of using the method effectively.

The hydrological perspective also establishes a reasonable foundation for the development of reduction activity. It is important that reduction activity for a water footprint is based on good hydrological knowledge to ensure crop productivity is maintained. Indeed it could be argued that a good hydrological basis for reduction work is the prerequisite for water footprints to be internationally accepted, especially by the hydrological research community. However, it should be noted that a negative blue water value could be used to hide poor practice by offsetting a high footprint grey water footprint. This should be avoided. If the methodology only produced zero to positive water footprint figures then it would be clearer and possibly more intuitive that reductions across all parts of the water footprint are required. So far, few studies of product water footprints using the WFN guidelines have been published and peer-reviewed in journals for hydrology, LCA, or ecological economics. Only a thorough discussion by the scientific community can prevent misinformation or bias of the impact measure on water resources. Such an event would be similar to what happened in the carbon debate of the impact of 'food miles' on climate change. In this case these issues provide a good foundation for future research activity in establishing and reducing water footprints for primary production in New Zealand.

Another important factor is the necessity to communicate the results to kiwifruit growers, other researchers, and policy makers so they can be used to devise a scientifically robust longer term strategy that is appropriate for managing the sustainable use of water resources. Further consideration of the hydrological perspective could help communicate important messages in reduction activity.

There are possible limitations to the hydrological approach. A criticism that may be levelled is that this approach allows a region to have a low or negative water footprint simply because that area experiences a lot of rainfall. An implicit assumption within the hydrological perspective is that every time it rains in a particular kiwifruit orchard blue water is accumulated in groundwater stocks. The implication of this assumption is that blue water is an environmental benefit for the system studied. Such assumptions regarding environmental impacts can be dangerous. For example, the effects of groundwater accumulation could be felt elsewhere in the catchment, e.g., raising water levels in an ecosystem downstream or increasing salinisation, as has been noted in Australia (A Fenemor, pers. comm., 31 January 2011). The use of water footprinting results often assumes that the lower footprint the better the result. However, having an optimum water footprint might provide more useful insight on how to improve orchard water management

Another potential drawback of the hydrological perspective could be in the communication of the results. A negative number for a water footprint, while theoretically possible (depending on how the footprint is calculated), might be difficult to communicate to consumers as it implies a product actually produces water within its cultivation or production. Such a misunderstanding would be easy to abuse and could eventually allow consumers to dismiss messaging about water footprinting as ‘green wash’. The communication of a negative water balance and whether such a figure would confuse consumers is another important issue for future discussion.

Orchard WFN water footprint

The consumptive water footprint for the WFN water footprint differs from the hydrological approach by excluding run-off and drainage (as described in section 8.3) and focusing only on evaporative blue water loss. The product perspective was calculated using the same dataset from the orchard survey and SPASMO modelling as the hydrological perspective discussed above.

In the consumptive water perspective green water is the water needed by the plant to grow the kiwifruit without irrigation, and excludes rainfall interception and plant run-off. WFN green water results range between 1059 l/TE in the Hawke’s Bay region and 1453 l/TE in the Northland region.

Irrigated crops have a blue water footprint due to the additional water applied to the crop during cultivation. In the consumptive water perspective the WFN blue water footprint describes the evaporative losses of blue water from green kiwifruit cultivation. The evaporative losses represent the water consumed or lost from the system during the growth of kiwifruit. Results for the WFN blue water range between 312 l/TE in the Hawke’s Bay region and 20 l/TE in the Katikati region. The weighted national average for all New Zealand kiwifruit growing regions is 62 l/TE for the orchard life cycle stage.

The analysis of the WFN grey water figures is the same as the figures calculated for each region in the hydrological perspective. The grey water results are based on the amount of water needed to reduce pollution by nitrogen fertiliser run-off to a 0.0 mg/l pristine level. Grey water results range between 37 l/TE in the Waikato region and 183 l/TE in the Katikati region. The weighted national average WFN grey water footprint is 156 l /TE.

In the consumptive water perspective, the total WFN water footprint for green kiwifruit orchards based on national average production is 1501 l/TE. Eighty-five percent of the total WFN water footprint is green water (soil moisture and other water available for plants at their location); 5% of total WFN footprint is blue water; and 10% of the total WFN footprint is grey water. The national average WFN water footprint per kilogram of green kiwifruit at the life cycle stage is 417 l. Assuming each kiwifruit weighs approximately 100 g, the national average water total WFN water footprint per green kiwifruit at the orchard is 42 l.

Orchard LCA impact assessment

In this study, the WFN water footprint was used to form the basis of results for modelling the LCA environmental impact by applying a freshwater ecosystem impact indicator. The FEI results for each of the green kiwifruit regions mirror the WFN blue results due to the use of a single national WUPR index (0.006) for the whole of New Zealand. The FEI results range between 0.12 in the Kaikati region and 1.87 in the Hawke's Bay region. The weighted national average FEI for green kiwifruit is 3.72.

Water stress may vary between different kiwifruit growing regions, and a further assessment was carried out using the regional WSI (Pfister et al. 2009). The regional results for evaporative blue water loss were multiplied by the relevant regional WSI to highlight potentially differences produced by different regional LCA characterisation factors

The application of the regional WSI to the evaporative blue water loss results provided a better basis for understanding the difference in in-country regional freshwater impacts. The WSI also highlighted in greater detail the differences between results produced using the WFN method and an LCA based approach.

The WFN water footprint, the FEI, and the WSI results all offer different interpretations of potential environmental impact of freshwater consumption at the orchard life cycle stage. However, in this study the use of the FEI indicator offered little extra value over and above the results provided by the WFN water footprint because of the use of a single national WUPR. In this situation, similar to the WFN water footprint, the value of the FEI indicator is for comparison of freshwater consumption impacts at the orchard in different kiwifruit producing countries.

In the WFN and LCA methods some problems have been encountered with communication of the methodology for the footprint to growers. Growers often feel the exclusion of rainfall flows other than those needed for plant growth leads to a misleading impression of the water footprint. The prevailing perception found among growers during the completion of the project is that rainfall is plentiful so there cannot be a problem with freshwater consumption even if freshwater abstraction is excessive at times. One problem then is that the consumptive water approach often seems counterintuitive to growers because it excludes certain green water flows.

The exclusion of green water and grey water from the environmental assessment of freshwater consumption highlights one of the difficulties with completing single issue footprints. Typically, it is argued that green water is best described in LCA by other environmental indicators in land-use change, and grey water by eutrophication impacts (Hume 2010). The omission of the green water and the grey water from the footprinting process is difficult to understand for many in the wider scientific community, including hydrologists and ecologists who have little experience of practical LCA application. While LCA remains a positive tool for assessing global environmental impacts caused by a product during the life cycle, its ability to describe a specific, localised impact such as freshwater consumption is still being developed.

10.2 Transport in New Zealand life cycle stages

Transport activities are normally not included in a water footprint except when the fuel used contains biofuel. As it is unlikely the trucks transporting kiwifruit regularly use biofuel, the water footprint of transport of kiwifruit between the orchard and packhouse has been excluded in this study. Transport of kiwifruit between the packhouse/coolstore has also been excluded.

10.3 Packhouse/coolstore operations

Three packhouse/coolstore operators were surveyed to establish their freshwater consumption during the project. Here results for WFN water footprint in this life cycle stage are focussed on the blue water use rather than on green or grey water. The green water footprint is not relevant at this life cycle stage because plant soil moisture is not part of the packhouse/coolstore system. It was not possible to establish the WFN grey water footprint at this life cycle stage from the data available. More information on the investigation of the grey water footprint of the packhouse/coolstore operation is provided in Appendix 5.

The total WFN water footprint for the packhouse and coolstore life cycle stage is 105.4 l/TE. The packing material used for a tray equivalent of green kiwifruit has a total WFN water footprint of 7.99 l/TE. Activities at the coolstore contribute 79 l/TE to the WFN water footprint at this life cycle stage. Eight percent of the total WFN water footprint is contributed by packing materials and 92% by the coolstore operations.

The collection of primary data for the materials used for packing green kiwifruit, and for the direct water use and electricity use by the packhouse/coolstores operators was straightforward. However, important assumptions had to be made to establish the WFN water footprint of the packing materials as information on freshwater consumption in the production of packing materials was not readily available. The water footprint of packing materials used for the kiwifruit export trays was based on the energy needed to make the materials; however, as it was not possible to separate blue water from grey water in the secondary sources it was only possible to calculate a total WFN footprint. Further inventory data are needed to establish an accurate WFN blue water footprint for packing materials used in the kiwifruit supply chain.

Virtually all (over 99%) the total WFN water footprint for the coolstore operation, excluding the packhouse, is dominated by the total WFN footprint for electricity use. Less than 1% of the total WFN footprint for the coolstore was derived from fuel and direct water use at the coolstore.

10.4 LCA packhouse/coolstore freshwater impacts

The WFN results described above were used to investigate potential environmental impacts using LCA. To provide an assessment to raise awareness and a basis for future research it was assumed that the WFN water footprint consisted entirely of blue water. Assuming also that evaporative blue water losses represent 15% of total water consumption based on Milà i

Canals et al. (2009), evaporative blue water loss from electricity use in the packhouse/coolstore amounts to 14.03 l/TE.

Evaporative blue water loss within the packhouse and coolstore was converted into environmental impact and results in an FEI of 0.084. A WSI of 0.0107 (for the Tauranga region of New Zealand) was used assuming electricity used is generated locally. Using a WSI 0.0107 leads to a regional WSI impact of 0.003.

10.5 Post-packhouse/coolstore life cycle stages

It was not possible to complete a WFN water footprint for all life cycle stages beyond the packhouse/coolstore operations. The following pages summarise the work completed to highlight important issues for further research. Many of the life cycle stages discussed below are examined through the WFN water footprint and LCA environmental impacts of freshwater consumption due to electricity use.

One major finding of the work on the post-packhouse/coolstore is that data for the WFN blue water footprint within different activities are often derived using different methods and inconsistent datasets. At the moment water footprinting research lacks a comprehensive source of data sources.

Departure port operations

The departure port for export grade kiwifruit is Tauranga in the Bay of Plenty. The information available from the previous carbon footprinting study in this life cycle stage was focussed on electricity use in port operations.

In this exploratory research it is sufficient to base the calculation of the WFN footprint on electricity use in this life cycle stage as there are few other obvious activities that would influence freshwater consumption.

The total WFN water footprint at the port based on electricity use is 1.91 l/TE. Evaporative blue water consumption based on a total 1.19 l/TE is 0.286 l/TE (assuming 15% evaporative blue water loss). Using the national WUPR of 0.006 for New Zealand, the evaporative blue water consumption produces an FEI impact of 0.002. Using a WSI 0.0113 (the WSI for the Tauranga region of the New Zealand) leads to a WSI impact of 0.003.

The results suggest departure port operations based on electricity use are probably not a significant to the water footprint and environmental of green kiwifruit.

Repacking in Europe

No data were available for energy use at the port or repackaging facility. Also no water footprint data were available for the production of polystyrene to make spifes. It was therefore not possible to establish the WFN water footprint for the European repacking operations without further investigation.

These elements of the supply chain water footprint need appropriate investigation in the future to establish an accurate water footprint of repacking activity in Europe.

UK Transport

The WFN water footprinting method recommends the inclusion of transport in a water footprint when biofuels are used due to the consumption of water during crop cultivation for fuel (Hoekstra et al. 2009). In this study biofuel use by a consumer passenger car used to pick up groceries from a local retailer was examined. The discussion on UK transport is used to highlight issues related to vehicle use of biofuels.

Current UK legislation sets a target for the inclusion of 3.25% biofuel by volume for both petrol and diesel for 2009/2010 (Renewable Fuels Agency, 2010). In this study it is assumed all biofuels used for car use is UK sourced. By using an example based on a passenger car travelling 11 km in total to a supermarket and back to pick up groceries it was possible to indicate a water footprint for UK transport within the supply chain. The WFN blue water footprint is 2.25 l/TE for the biofuels used in the passenger car. The WFN blue water footprint was then used to calculate the potential environmental impact of an FEI of 0.15. In order to assess the environmental impact using a regional WSI, the location of the biofuel crop cultivation is needed; as an example, the WSI listed for Cambridgeshire and Lincolnshire. Using the WSI 0.1481 results in a regional WSI impact of 0.33.

In this study neither the distribution of fruit via heavy goods vehicle or light goods vehicles has a relative large contribution to environmental impacts from freshwater consumption. The WFN blue water footprint for distribution of kiwifruit in the UK is 0.84 l/TE, producing impacts of FEI 0.05 and WSI of 0.12.

UK retailer

The UK retailer was examined through energy use and made a relatively small contribution to freshwater consumption and the environmental impact of the green kiwifruit supply chain. Unless further evidence becomes available that suggests this life cycle stage could be important for water footprinting it is unlikely this stage will be significant for future studies.

UK household consumption

The household consumption life stage and its relevance to the kiwifruit supply chain are discussed largely through electricity use and limited data from the literature on wastewater generation from households.

Based on Milà i Canals et al. (2010), blue water evaporative loss from hand drying is 0.06 l/TE. Blue water evaporative loss from electricity use results in FEI 0.004. Using a WSI 0.0107 (for western Wales) results in a 0.006 regional impact.

If green kiwifruit were assumed to generate the same wastewater amounts as broccoli (per kg) and tap water used in the household is considered to be blue water in both WFN and LCA methods, a basic indicator of the water footprint at this life cycle stage can be established. Based on the generation of 25 l of wastewater, blue water evaporative loss for excretion of fruit is 11.58 l/TE. Added to the evaporative loss for electricity use in the home, total blue water evaporative loss is 11.64 l/TE. Blue water evaporative loss due to household water use results in FEI 0.76.

The consumption of water at different households in different parts of the UK is likely to have differing environmental impacts. Using the regional WSI it is possible to make an in-country comparison of environmental impact. Using a WSI for Skelton in Scotland of 0.01, the regional impact is 0.12, and using a WSI for London of 0.9956 results in 11.59 regional impacts.

The results provided in this study are not comprehensive, and the assumptions made limit the value of the research. For example, kiwifruit can be distinguished from broccoli because kiwifruit do not typically require cooked before eating so the contribution of the household stage to the water footprint is likely to be lower. More specific data and guidance are needed for the water footprint wastewater generated in the household life cycle stage to increase the accuracy of future research. For example, the information in the literature tends not to include liquid intake, which usually determines the frequency of toilet use and in turn water use in these circumstances.

10.6 Cumulative environmental impacts

It is normal in both WFN and LCA approaches to consider the cumulative effect of the environmental impacts across the entire supply chain. In the LCA approach the additional environmental impacts associated with the losses of fruit within the supply chain would also be considered. As in Mithraratne, (2010) it should be expected that losses of fruit at the packhouse/coolstore, at the New Zealand departure port, and in European repacking activities would increase the environmental impacts associated with the WFN and LCA based water footprints for the green kiwifruit life cycle.

Despite it being possible to express a high degree of confidence in the water footprint at the orchard life cycle stage, the numerous gaps and omissions in the research mean a total water footprint figure that covers all life stages for green kiwifruit was not produced. A simplified analysis is presented below in section 10.7 based on blue evaporative water loss in the supply chain rather than consideration of the total WFN water footprint.

Given the limitations of the research it is difficult to gauge the accuracy and validity of any figure produced, and it is possible the large number of assumptions needed to complete research would render a single total figure virtually meaningless. In the circumstances the value in attempting to link the different life cycle stages and measure the impact of losses quantitatively to produce a total WFN footprint for the supply chain is diminished.

10.7 The importance of different life cycle stages

The orchard stage is usually highlighted as one of the most important stages in a water footprinting exercise of primary products (Hume 2010). The WFN blue water and LCA freshwater consumption environmental impacts at the orchard life-cycle stage are often small, even when irrigation water is applied to the crop. For example, in the Te Puke region, a major green kiwifruit production region, the WFN blue water footprint is just 22 l/TE or 6 l/kg green kiwifruit in the orchard stage.

The relatively low WFN blue water footprints for green kiwifruit at the orchard stage in many regions raises the possibility that other stages in the life cycle might also be important for the life cycle-based water footprint. However, it was not possible to fully investigate the downstream life cycle stages beyond the packhouse/coolstore in this exploratory study. In this case it is difficult to gauge the significance of these stages to overall water footprint. It is therefore recommended that a number of downstream life cycle stages are investigated further in the future, including repacking operations, distribution of the product within the UK, and household consumption.

Figures 21, 22, 23 and 24 summarise the evaporative blue water loss and FEI and WSI environmental impacts for the green kiwifruit supply chain in this study. When viewed together the bar graphs show that the importance of freshwater consumption at the orchard life cycle stage. The second life cycle stage that is worthy of further attention is the household consumption life cycle stage.

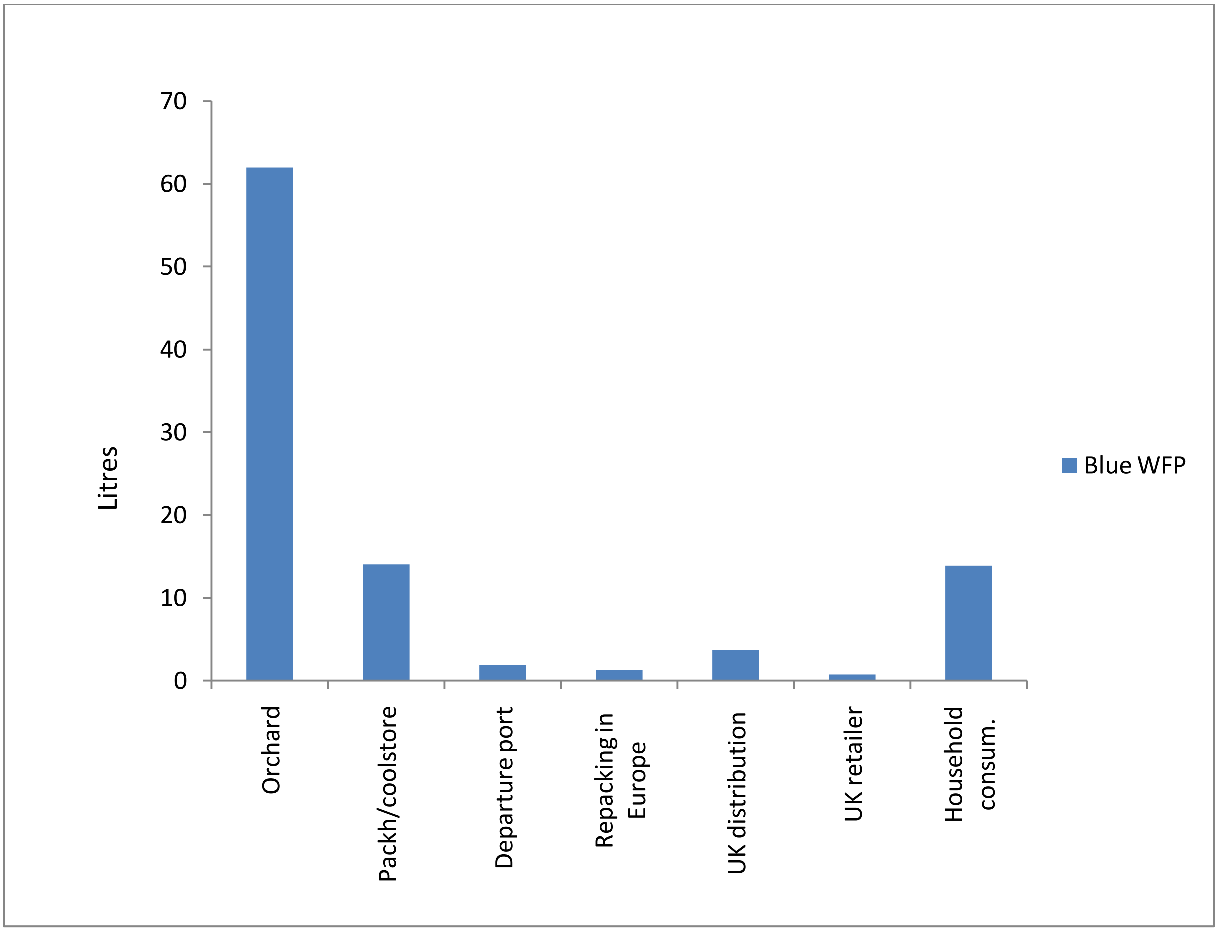

Figure 21 WFN based evaporative blue water loss in the kiwifruit supply chain. Note several stages in the life cycle are represented by freshwater consumption in electricity use only.

The pattern of FEI results is similar to that shown by the evaporative blue water loss but characterisation reduces the importance of the packhouse and coolstore stage. The application of the WSI also reduces the relative importance of the packhouse/coolstore life cycle stage. Total evaporative blue water across the supply chain is 97.59 l/TE. Based on the evaporative water results listed above total environmental impacts described by FEI is 4.98.

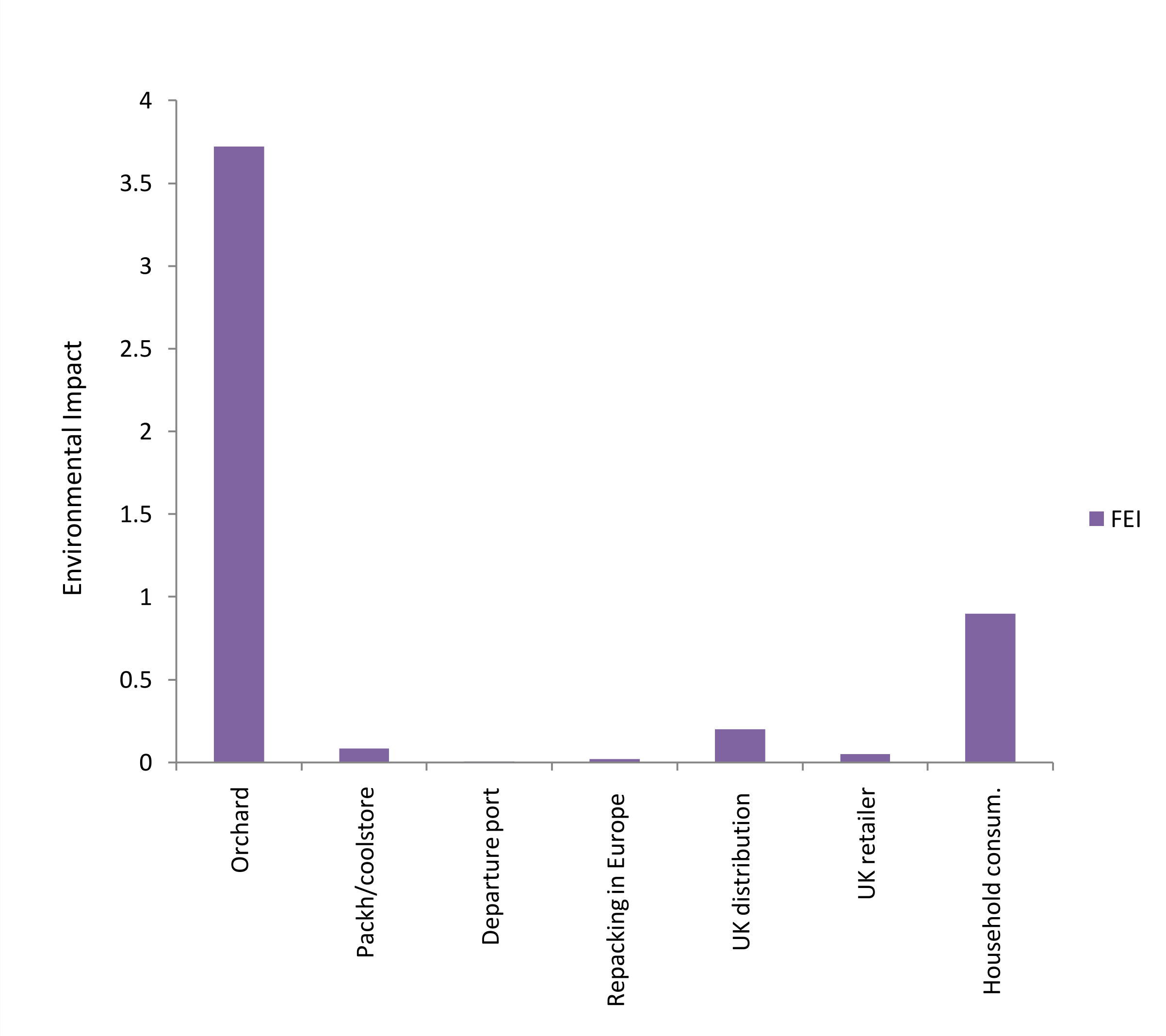

Figure 22 Freshwater Ecosystems Impact (FEI) across the life cycle stages of the green kiwifruit supply chain.

Figures 23 and 24 emphasise the importance of geographic location for the environmental impact of freshwater consumption. Depending on where green kiwifruit is consumed, the importance of the household consumption life cycle stage can change. Figure 23 shares a similar pattern across the supply chain as evaporative blue water loss and FEI. Here the water stress is low as kiwifruit is assumed to be eaten in Scotland. In Figure 24 the high water stress in London increases the relative importance of the household consumption life cycle stage.

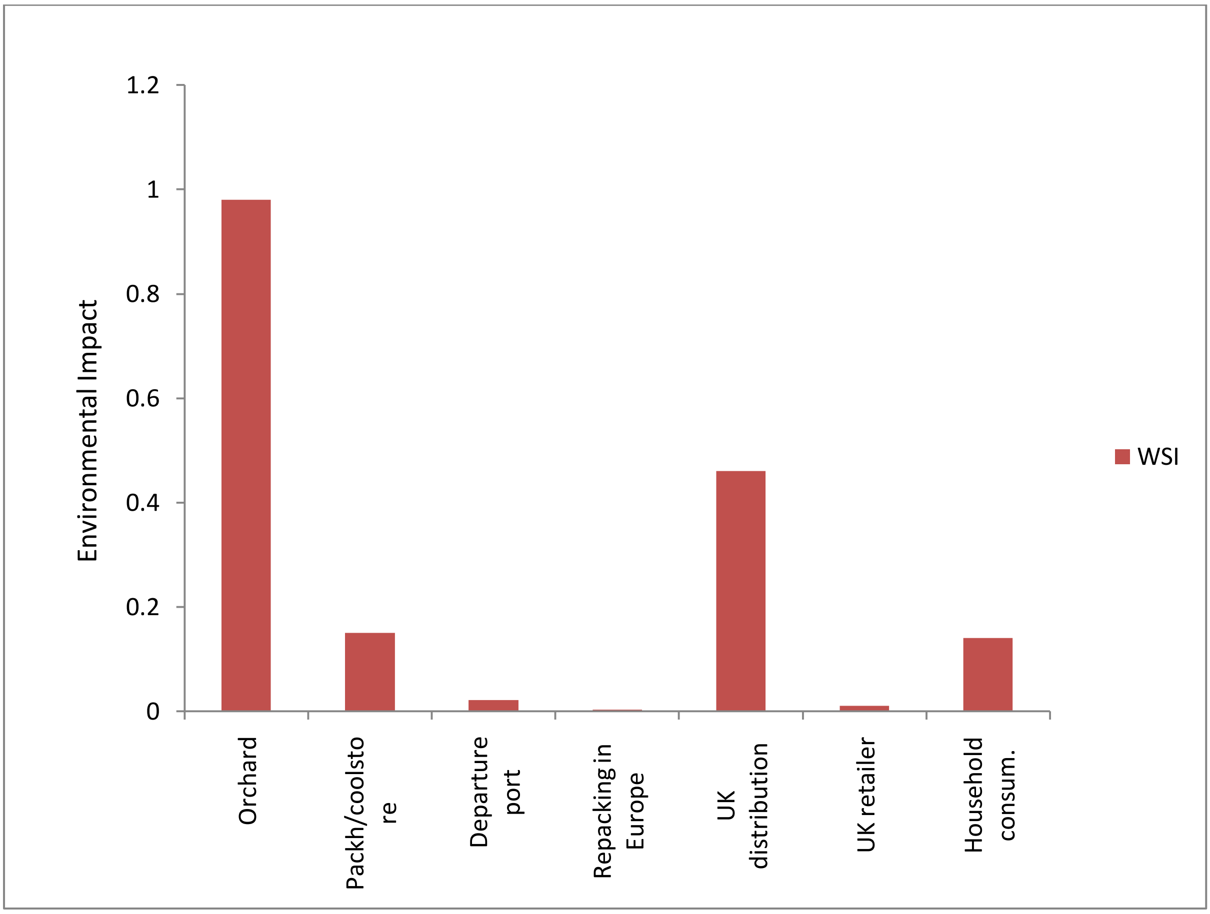

Figure 23 The WSI across the kiwifruit supply chain with household consumption in Skelton, Scotland UK.

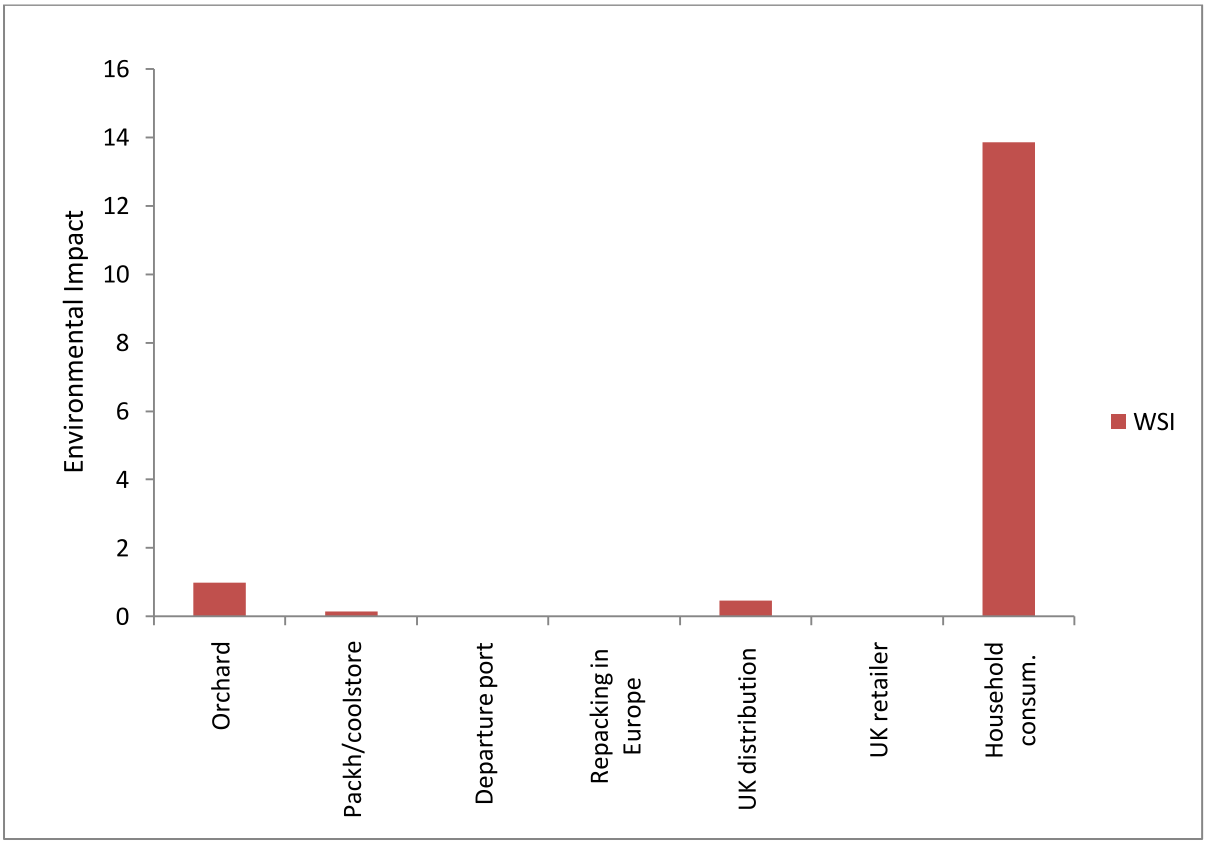

Figure 24 The WSI across the kiwifruit supply chain with household consumption in London, UK.

The total WSI for the supply chain ranges between 1.76 if the kiwifruit is eaten in Skelton in Scotland and 15.76 if the kiwifruit is consumed in an area of high water stress, e.g., London.

10.8 WFN vs. LCA water footprinting

One of the aims of the project was to investigate and compare the results of the WFN and LCA methods. The most comprehensive data obtained during the research were at the orchard life cycle stage. From the work completed in the project it is difficult to say definitively if one method is better than the other for describing the environmental impact of freshwater consumption.

It has to be noted that the discussions within the International Standards Organisation (ISO) on the development of international water footprinting standard are centred on using a life cycle perspective (S. McLaren, pers. comm., 18 August 2008). Both LCA and WFN take a life cycle perspective in terms of product assessment. Both LCA characterisation factors used in this research are based on establishing a blue water footprint that can be facilitated by the consideration of the WFN method as a first step. Therefore it would appear that as a strategic business tool the WFN method still has a significant role to play in the development of water footprinting.

Each method has it pros and cons and both would benefit from a greater number of case studies and the provision of data specific for water footprint calculation. In reality, both WFN and LCA methods often share the same secondary data sources. However, each method has revealed useful information about freshwater consumption in New Zealand green kiwifruit orchard activities. For example, the results in WFN footprint show the majority of freshwater consumed in the cultivation of green kiwifruit is from green water sources. As noted in Berger and Finkbeiner (2010), establishing green water consumption is particularly important for the discussion of agricultural crops because it highlights crops that are rainfed rather than cultivated by irrigation. To add to the WFN findings characterisation of the results using the WSI highlighted the disproportionately large contribution to environmental impacts of regions, e.g., Auckland, that provide relatively small contributions to the national production of green kiwifruit.

The WFN results appear more aligned to communication of water footprinting results with consumers. For example, a water footprint of 42 l per green kiwifruit is easier to understand by the lay person than any of the other water footprint results obtained in the LCA methods used.

Methods for the measurement of the WFN grey water footprint are still in development. Useful data for the measurement of the WFN are not readily available in most cases and the grey water footprint is often excluded from published WFN results (SABMiller 2009). In the orchard life stage it was possible to establish a grey water footprint, but the process did highlight a number of issues with the correct method and fresh water standards to use. For example, the WFN grey water footprint can be determined using at least five different New Zealand water quality standards. In this study a cautious approach has been used but using less strict standards could lead to lower quantities of grey water being described for the same product at the orchard.

Use of characterisation factors for New Zealand taken from Milà i Canals et al. (2009), other than for providing a measure of environmental impacts for each kiwifruit cultivation region, provides little extra value over the WFN results without the need for further analysis. As only national characterisation factors are available for FEI it appears best used in this case when production of green kiwifruit is compared with orchard freshwater consumption in another country. The application of the WSI to blue water evaporative loss results provided a different pattern of environmental impacts for freshwater consumption, highlighting environmental impacts within different kiwifruit growing regions in New Zealand.

The WSI has the potential to inform strategic responses within the industry for reduction of freshwater consumption impacts by identifying issues to be targeted after being assessed by a wide range of factors, for example, population density, and domestic freshwater consumption demands. However, the WSI by its regional nature was difficult to apply to the data for the New Zealand electricity grid system and in situations where averaged data for a country-wide area is used. For example, the water footprint of an electricity grid would need to take into account the WSI index at a sample of electricity generation sites. For ease of reference in this study the WSI from one region was simply applied to evaporative blue water loss results.

11 Recommendations

At numerous points throughout this document potential areas for future research have been highlighted. There is little doubt that the provision of key pieces of basic data would boost the accuracy and acceptance of New Zealand water footprinting studies. For example, an agreed WFN blue water footprint of New Zealand electricity could be used by a wide range of water footprint studies. Data generated for future studies for the time being should be based both on the WFN and LCA methods, as most LCA methods require blue water results to be provided before characterisation into environmental impact. This approach would also ensure maximum flexibility for use with the ISO standard on water footprint currently under discussion.

In particular, this exploratory research has shown further work is needed to refine:

- The best methods for collection of data at the orchard life cycle stage. The orchard survey in this research could not be completed without considerable input from the research team. For widespread water footprinting to become practical data templates listing essential information for collection should be developed to help growers.
- The accurate use and maintenance of water meters. During the orchard survey it was found that water meters were poorly maintained and calibrated. For accurate water meter measurements to be used in water footprinting the meters must be maintained and information recorded regularly.
- Knowledge of freshwater losses due to reticulation (losses in piping or pumping from source) at the orchard life cycle stage.
- Attempts to support water footprinting using water modelling of local systems including simplified water balance models similar to the hydrological perspective. The use of modelling tools at a sector level could potentially reduce the burden of data collection for different parts of the kiwifruit supply chain.
- Freshwater consumption in the production of packaging. This study has underestimated the size of the water footprint for packaging materials due to the lack of readily available data on pulping and processing activities.
- Freshwater consumption in repacking activity and information relating to repacking and coolstore activity. Providing a better understanding of whether the assumption repacking activities are similar to New Zealand packhouse/coolstore activities would be an improvement on the current situation.
- Research into the footprint of biofuels used in distribution of green kiwifruit within the UK by retailers. The best method to achieve this might be to work with UK retailers such as Sainsburys or non-governmental organisations who are interested in increasing the use of water footprinting for products.
- Data for the water footprint of retailer activities. A useful piece of data for further supply chain investigations would be the water footprint of the New Zealand and UK electricity grid systems. The best methods for applying WSI to electricity grid systems should be given greater consideration, e.g., average WSI values for New Zealand could be obtained using GIS software by weighting the regional values based on their relative area contribution to the country total freshwater consumption.
- Understanding of the relationship between storage time, fruit loss and the influence of these factors throughout the whole supply chain.
- The use of the WSI and its application to regional orchard water footprinting. In this research it was beyond the scope of the report to fully apply the method for environmental impact assessment from Pfister et al. (2009).
- The communication of water footprint results using methods that all members of the supply chain can understand and use in a practical manner.

12 Acknowledgements

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Appendix 1 Sample orchard inventory report

ZESPRI Inventory Report

Printed at June 2, 2010 08:21

KPIN:	XYZ	Canopy Area:	xx.xx ha
Titleholder Name:	XYZ		
Variety:	HAYWARD	Growing Method:	Conventional
Faciltiy:	XYZ		

Year to Date: 2 Jun, 2010

2007 Kiwifruit Season

Comparative Data	Your Average		Industry Average		Industry Top 25%		Industry Lower 25%	
	2007	2006	2007	2006	2007	2006	2007	2006
Size	37.06	34.10	34.63	31.83	33.00	27.00	39.00	36.00
TZG	0.36	0.47	0.50	0.43	0.57	0.51	0.43	0.36

Click to view TZG by Maturity Area

Class 1 HAYWARD Conventional

Volume (trays) – as at midnight the previous day; includes Standard and Non-Standard Supply

	Size									
	Total	22	25	27	30	33	36	39	42	46
Gross Submit	171,893	276	1,250	3,977	8,443	20,874	50,468	54,759	30,598	1,248
Fruit Loss (Chargeable)	7,572	61	26	242	465	242	1,297	2,590	2,084	566
Fruit Loss (Non-Chargeable)										
Net Submit (YTD)	164,320	215	1,224	3,735	7,978	20,633	49,171	52,168	28,514	682
Shipped	164,320	215	1,224	3,735	7,978	20,633	49,171	52,168	28,514	682
% Shipped of Net Submit (YTD)	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
In Store	0						0	0		

Click to view Gross Submit by Size by Week (including UFI and Trays Packed) - Real Time Report

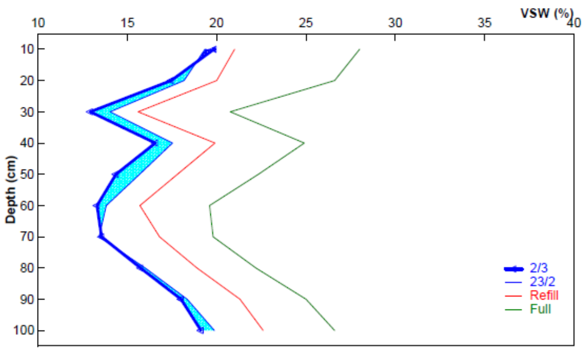
Click to view Trays Shipped by Size by Week, Industry Average and Your Region - Real Time Report

Other Volume Supplied to ZESPRI (Trays) - (Included in the Calculation of the Production Cap for Voting Rights)

	Size							
	Total	22	27	30	33	36	39	42
Class II (K1W1)	20,401	96	622	882	1,894	5,507	6,314	5,086

	Size	
	Total	46
Non Standard Supply (NSS)	1,248	1,248

Appendix 2 Sample orchard end of season report

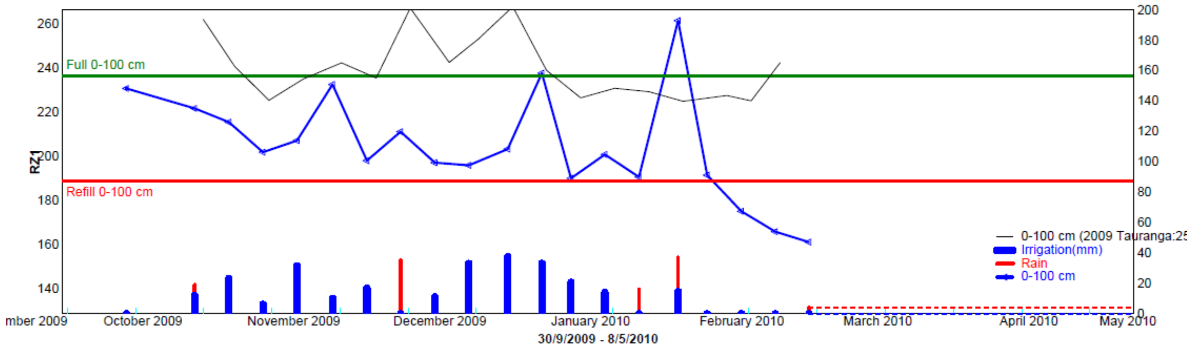


Season Summary

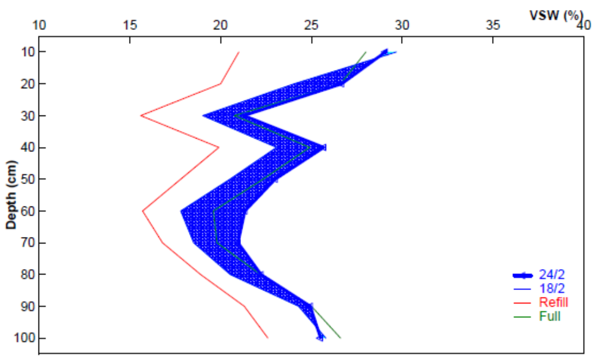
RootZone	0-100 cm
Full Point	236 mm
Refill Point	189 mm
FAW	48 mm

Irrigations	mm	L
Delivered:	263	5990
Effective:	263	5990
Efficiency:	100%	

Rain		
Delivered:	161	3669
Effective:	98	2233
Efficiency:	61%	



One orchard’s 2009/10 season summary irrigation monitoring report showing the soil moisture profile, irrigation, and rainfall.

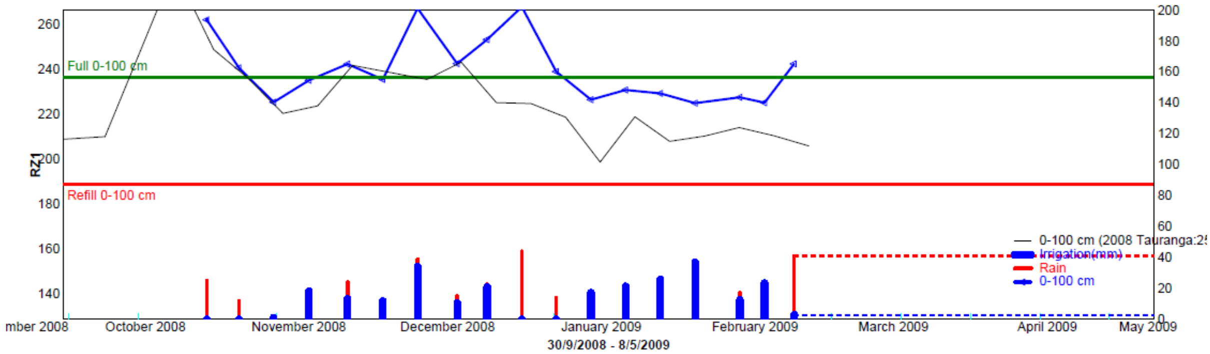


Season Summary

RootZone	0-100 cm
Full Point	236 mm
Refill Point	189 mm
FAW	48 mm

Irrigations	mm	L
Delivered:	249	5682
Effective:	239	5441
Efficiency:	96%	

Rain		
Delivered:	296	6746
Effective:	90	2046
Efficiency:	30%	



Appendix 3 Survey form for packhouse/coolstore operations

Name of packhouse		
Location		
Period Chosen for Data Collection	Year 2009/10 (April to April)	
Packhouse details	Size of packhouse	
	Source of water (e.g., tap, bore or rainwater)	
	Recycling of used water?	
	Used water is discharged to?	
Contact Person and Phone Number		

Please provide details of products other than kiwifruit handled by the packhouse, and how long it was vacant during that year.

Product	Total quantity (kg)	Percentage volume/area of packhouse dedicated to the product	Length of stay (days, weeks or months)

2. Total Quantity of Kiwifruit Processed At Packhouse

Variety	Total number of TE[1] received	Number of TE export quality fruit sent to port (Class 1)	Number of TE returned from port	Number of TE non-export quality fruit sent to market (Class 2)	Number of TE of waste fruit
ZESPRI® GREEN					
ZESPRI® GOLD					

[1]Confirm Tray equivalents to mean 3.6 kg of kiwifruit

3. Distribution of pack types for class 1 kiwifruit sent to port

	Class 1 ZESPRI® GREEN kiwifruit sent to port	Class 1 ZESPRI® GOLD kiwifruit sent to port
Pack type	% of total number of TE sent to port	
International tray (IT)		
Modular loose box (ML)		
Modular double box (M2)		
Modular bulk box (MB)		
Plateau box (P1)		

4. Waste Fruit

Please provide details of fruit wastage at the packhouse and the quantity of waste disposed of using each method. If the method of disposal used is not listed, please include it as a note below the table.

Variety	Number of TE of wastage (from last column of previous table)	TE sold as feedstock		Number of TE sent to process	Number of TE sent to landfill
		Number of TE	Price per TE sold as feedstock		
ZESPRI® GREEN					
ZESPRI® GOLD					

Note: Includes losses from repacking

5. Direct use of water

	Quantity (m^3)	Activities associated with this meter (e.g. packing line, toilets, cleaning of bins)	Notes
Meter 1			
Meter 2			
…			

Note: We need to subtract the staff water use from the total water use as staff water use is not considered in water footprint of kiwifruit calculations. Please list here shortly how many staff you employ for how many days (e.g., 200 people for 60 days for main packing,…)

6. Fuel use

Please complete the table below on fuel use data for activities in the packhouse. Add any other oils or fuels used which are not listed below. Possible activities are the use of forklifts, administration etc.

Fuel type	Total quantity (litres)	Activities using this fuel
Diesel		
Petrol		
Lubricants		
LPG		
…		
…		

7. Electricity Use

Please list details for all electricity meters if packhouse has more than one meter.

	Quantity (kWh)	Activities associated with this meter (e.g. packing line)	Notes
Meter 1			
Meter 2			
…			

Note: If you have only one electricity meter for packhouse and coolstore then please explain how you derived the electricity for the packhouse (e.g., assumed 50% for packhouse and 50% for coolstore).

8. Packing for Export Quality Fruit

Please provide details of packing materials used. Add any other items not included in the list. It is especially important to cover any items made from cardboard, paper or plastic, as those materials have relatively high water footprints.

Item	Material[1]	Weight of single item	Total quantity purchased in year	Total quantity used in year
Tray, boxes	Cardboard			
Pallet caps	Cardboard			
Strapping	PP			
Plastic liners or pocket bags	HDPE			
Plixes	PET			
Pallets	Wood			
Bins	Wood			
Pallet caps	Wood			
Photocopier/printer paper	Paper			

Note: This should include wastage.

9. Transport from/to packhouse

Transport	Vehicle type	Distance (one way)	Number of trips	Return empty?
Fruit orchard to packhouse				
Pellets to port				
Waste to landfill				
Waste to farm and process				
Packing materials to packhouse				

Survey form for coolstore

Name of coolstore		
Location		
Period Chosen for Data Collection	2009/10 (April to April)	
Coolstore details	Size of coolstore	
	Source of water (e.g. tap, bore or rainwater)	
	Cooling system: separate or central refrigeration system?	
	Type of refrigeration technology	
	Recycling of used water?	
	Used water is discharged to?	
Contact Person and Phone Number		

Please provide details of products other than kiwifruit handled by the coolstore, and how long it was vacant during that year.

Product	Total quantity (kg)	Percentage volume/area of coolstore dedicated to the product	Length of stay (days, weeks or months)	Typical temperature for product

2. Total Quantity of Kiwifruit Processed At Coolstore

Variety	Total number of TE[1] received	Number of TE export quality fruit sent to port	Number of TE returned from port	Number of TE non-export quality fruit sent to market	Number of TE of waste fruit
ZESPRI® GREEN					
ZESPRI® GOLD					

[1]Confirm Tray equivalents to mean 3.6 kg of kiwifruit

Note: For a combined packhouse/coolstore the results here are identical to the packhouse survey.

3. Distribution of pack types for class 1 kiwifruit sent to port

	Class 1 ZESPRI® GREEN kiwifruit sent to port	Class 1 ZESPRI® GOLD kiwifruit sent to port
Pack type	% of total number of TE sent to port	
International tray (IT)		
Modular loose box (ML)		
Modular double box (M2)		
Modular bulk box (MB)		
Plateau box (P1)		

Note: For a combined packhouse/coolstore the results here are identical to the packhouse survey.

4. Waste Fruit

Please provide details of fruit wastage at the coolstore and the quantity of waste disposed of using each method. If the method of disposal used is not listed, please include it as a note below the table.

Variety	Number of TE of wastage (from last column of previous table)	TE sold as feedstock		Number of TE sent to processing	Number of TE buried on site
		Number of TE	Price per TE sold as feedstock		
ZESPRI®					

GREEN					
ZESPRI® GOLD					

5. Coolstore Processes Related To Kiwifruit

(Please fill in and add any additional activities not listed below.

Process	Fruit variety	Duration (days)			Notes
		Minimum	Maximum	Average (estimated)	
Cool storage	ZESPRI® GREEN				
	ZESPRI® GOLD				
Storage of packed fruit under CA	ZESPRI® GREEN				
	ZESPRI® GOLD				
…					

6. Direct use of water

	Quantity (m^3)	Activities associated with this meter (e.g., coolrooms, toilets, etc.)	Notes
Meter 1			
Meter 2			
…			

Note: We need to subtract the staff water use from the total water use as staff water use is not considered in water footprint of kiwifruit calculations. Please list here shortly how many staff you employ for how many days (e.g., 200 people for 60 days for main packing,…)

7. Fuel use

Please complete the table below on fuel use data for activities in the coolstore. Add any other oils or fuels used which are not listed below.

Fuel type	Total quantity (litres)	Activities using this fuel
Diesel		
Petrol		
Lubricants		
LPG		
…		
…		

8. Electricity Use

Please list details for all electricity meters if coolstore has more than one meter.

	Quantity (kWh)	Activities associated with this meter (e.g., coolroom)	Notes (e.g., capacity/throughput of this coolroom)
Meter 1			
Meter 2			
…			

Note: If you have only one electricity meter for packhouse and coolstore then please explain how you derived the electricity for the coolstore (e.g., assumed 50% for packhouse and 50% for coolstore).

9. Technical details of coolstore

Technical detail	Yes/No plus notes
Evaporative condensers? What type of water discharge system (e.g. bleed off or sump dump) for condensers?	
Water or electricity defrost?	
Monitoring systems for electricity (or water)	
External cooling for compressors	
Strip curtains, rapid roller or slide doors?	
Variable Speed Drives for compressors?	
Do you use load shedding?	
Flexible defrost management?	
Regular maintenance programme implemented?	

Appendix 4 Estimation of water footprints of input materials for packhouses and coolstores

Currently, existing life cycle inventories (e.g., Ecoinvent) do not provide water footprints for materials or activities. Therefore, we had to estimate the water footprint of input materials (e.g., cardboard) based on other data.

Only the evaporative loss of direct water use needs to be considered, and, following l. Milà i Canals et al. (2010) we estimated this to be 5% of the direct water use (Table A4.1).

We assumed that other important components of the water footprint of any material are the amounts of energy carriers (e.g., coal, crude oil, natural gas, hydroelectricity; Table A4.1) involved in its manufacture. The water footprints of various energy carriers (see footnotes to Table A4.2) have been recently estimated (Gerbens-Leenes et al. 2008).

The amounts of direct water use and energy carriers for the various input materials (Table A4.1) were taken either from the Australian Life Cycle Inventory Project or from the ecoinvent database (v2.2).

It was beyond the scope of this project to estimate and include the water footprints of all raw materials other than water and the energy carriers that are involved in the manufacture of the input materials for the packhouse and coolstore phases.

The water footprints of the energy carriers also integrate a grey water footprint. However, we did not consider the grey water footprint resulting from the various emissions to water during the manufacture of the input materials (see Appendix 5).

Table A4.1 Water-footprint (blue and grey) relevant raw material inputs for input materials for the packhouse and coolstore phases

Input materials for packhouse and coolstore phase	Raw material input in kg per kg of input material				
	Coal	Crude oil	Natural gas	Hydro-electricity	Water
	[kg/kg]	[kg/kg]	[kg/kg]	[kJ/kg]	[kg/kg]
Wood[1]	0.00131	0.0374	0.005	1.14E+03	0.007
Cardboard 100% recycled [2]	0.109	0.022	0.297	531	7.11
Cardboard 75% Virgin[3]	0.133	0.014	0.273	654	4.18
Paper[4]	0.426	0.1163	0.240	1.95E+03	Not specified

Input materials for packhouse and coolstore phase	**Raw material input in kg per kg of input material**				
	Coal	Crude oil	Natural gas	Hydro-electricity	Water
	[kg/kg]	[kg/kg]	[kg/kg]	[kJ/kg]	[kg/kg]
PP[5]	0.00047	1.46	0.183	147	0.679
PET[6]	0.018	1.58	0.222	46.3	0.680
HDPE[7]	0.0008	0.18	1.16	0.233	1.31
Petrol[1]	0	1.27	0.067	0	0.015
Diesel[1]	0	1.22	0.065	0	0.014
Lubricants[1]	0	1.22	0.065	0	0.014
Refrigerant HCFC 22[8]	0.695	0	1.0885	0	0.202

[1] Amounts of raw materials were taken from the aggregated product inventory of 'Structural Pine' (Todd et al. 1999)

[2] Amounts of raw materials were taken from the aggregated product inventory of 'Corrugated board (brown) 100% Recycled' (Grant et al. 1999)

[3] Amounts of raw materials were taken from the aggregated product inventory of 'Corrugated board (brown) 75% Virgin' (Grant et al. 1999)

[4] Amounts of raw materials were taken from the aggregated producti inventory of 'paper, wood containing' from the ecoinvent database (v2.2)

[5] Amounts of raw materials were taken from the aggregated product inventory of 'Polypropylene (PP) Australia Average' (Tabor et al. 1998a)

[6] Amounts of raw materials were taken from the aggregated product inventory of 'Polyethylene Terephtalate (PET97) Crystalline' (Tabor et al. 1998b)

[7] Amounts of raw materials were taken from the aggregated product inventory of 'High Density Polyethylene' (Grant et al. 1998)

[8] Amounts of raw materials were taken from the aggregated product inventory of 'HFC-22' from the ecoinvent database (v2.2)

Table A4.2 Water footprints of packing materials estimated from raw material inputs (Table A3.1) and water footprints of some other inputs of the packhouse phase (e.g. LPG, electricity)

Input material	Water footprints of raw material inputs in l of water footprint per kg of input material or activity					Water footprint of input material (gray water footprint only partly included)
	Coal[1]	Crude oil[2]	Natural gas[3]	Hydro-electricity[4]	Water[5]	
	[l/kg]	[l/kg]	[l/kg]	[l/kg]	[l/kg]	[l/kg]
Wood	0.004	1.662	0.029	25.422	0.00035	27.1
Cardboard 100% recycled	0.393	0.978	1.748	11.841	0.355	15.3
Cardboard 75% Virgin	0.48	0.622	1.607	14.584	0.209	17.5
Paper	1.537	5.168	1.413	43.485	-	51.6
PP	0.002	64.877	1.077	3.278	0.034	69.3
PET	0.065	70.209	1.307	1.026	0.034	72.6
HDPE[1]	0.003	7.998	6.828	5.196	0.066	20.1
Petrol	0	56.433	0.394	0	0.0075	56.8
Diesel	0	54.212	0.380	0	0.0007	54.6
Lubricants	0	54.212	0.380	0	0.0007	54.6
Refrigerant HFC-22	2.508	0	6.407	0	0.01	8.9
Electricity	-	-	-	-	-	158.76 l/kWh[7]
LPG[6]	-	-	-	-	-	5.9

[1] The total water footprint of coal is 164 l/GJ (Table 3 of Gerbens-Leenes et al. (2008)), and we assumed an energy density of 0.022 GJ/kg of coal

[2] The total water footprint of crude oil is 1058 l/GJ (Table 3 of Gerbens-Leenes et al. (2008)), and we assumed an energy density of 0.042 GJ/kg of crude oil

[3] The total water footprint of natural gas is 109 l/GJ (Table 3 of Gerbens-Leenes et al. (2008)), and we assumed an energy density of 0.054 GJ/kg of natural gas

[4] The total water footprint of hydroelectricity is 22,300 l/GJ (Table 3 of Gerbens-Leenes et al. (2008)), and we assumed an energy density of 0.278 kWh/MJ

[5] Following Canals et al. (2010) we estimated the water footprint of direct water use as 5% of the direct water use

[6] We estimated the water footprint of LPG to be identical to natural gas (Table 3 of Gerbens-Leenes et al. (2008))

[7] According to A. Hume (pers. comm., 2010).

References

Milà i Canals LM, Chapagain A, Orr S, Chenoweth J, Anton A, Clift R 2010. Assessing freshwater use impacts in LCA, part 2: case study of broccoli production in the UK and Spain. Journal of Life Cycle Assessment DOI 10.1007/s11367-010-0187-0.

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Appendix 5 Estimation of grey water footprints of input materials for packhouses and coolstores

The LCI (Life Cycle Inventory) database of Todd et al. (1999) was used to infer the grey water footprints of the background system of packaging and products used in packhouses and coolstores. For consistency, just this single LCI database was used. In attempting to determine the grey water footprints in the background system, two general issues were realised:

- There was no information of the discharge volumes to the environment for certain products in Todd et al. (1999). There is no LCI information on effluent discharges for wood, and for green kiwifruit the packhouse/coolstores use some 124 g-wood per tray. It is therefore not possible, as far as we could obtain LCI data, to calculate the grey water footprint associated with some products.
- The second problem we encountered was that even where LCI data for the effluent discharges associated with packaging products exist, we had no information as to whether indeed these discharges were to the natural environment at those concentrations, or whether there was some intervening water treatment process to enhance discharge-water quality.

Here we discuss in more detail the grey water footprint of two packaging products for which discharge volumes are given in Todd et al. (1999), namely cardboard and PET (polyethylene terephthalate). For each of these we explore the grey water footprints in relation to a number of contaminants. Assessment of their effluent concentrations, c_{eff}, in relation to the trigger levels, $c_{\max}$, leads us to infer whether or not water treatment would be required.

The Resource Management Act (1991) (RMA) requires consents for contaminant discharges (section 70) and there must be mitigation of any adverse effects on the environment (section 5), say by wastewater treatment. This would apply to the cardboard and wood packaging used in kiwifruit packhouses and coolstores for this is sourced from New Zealand. Such packaging comprises some 93% of the water footprint of the background system for packaging. As the plastic packaging is sourced from overseas, we cannot be sure what environmental standards or regulations would have been enforced, nor do we know whether the wastewater is discharged to water bodies, or applied to land for treatment. But our exploration of the potential size of the grey water footprint of the background system is instructive and highlights the need for better LCI data.

The grey water footprints of cardboard (75% virgin)

Todd et al. (1999) suggest that the production of 1 kg of corrugated brown cardboard produces 0.524 l of polluted water and they listed the concentrations of some 70 or so contaminants in this wastewater. Selected contaminant grey-water concentrations are listed in Table A5.1, along with the trigger values to protect 95% of species as provided by ANZECC (2000) for the slightly to moderately disturbed ecosystems of New Zealand’s lowland rivers. Of the selected contaminants, all are below the ANZECC trigger values except phosphate, and below we discuss in more detail the impact this would have on the grey water footprint if it were actually discharged directly into a lowland river without treatment.

Table A5.1 Contaminants considered in grey water analysis

Contaminant	Concentration	ANZECC Value	Exceedance?
2,4,6-trichloroethylene	32.44 pg l^{-1}	20 μg l^{-1}	☒
Ammonia	7.47 μg l^{-1}	21 μg l^{-1}	☒
Arsenic	4.52 μg l^{-1}	24 μg l^{-1}	☒
Cadmium	11.60 μg l^{-1}	0.2 μg l^{-1}	☑
Copper	31.68 μg l^{-1}	1.4 μg l^{-1}	☑
Cyanide	1.18 μg l^{-1}	7 μg l^{-1}	☒
Nitrate	848.9 μg l^{-1}	444 μg l^{-1}	☑
Phosphate	32951.45μg l^{-1}	33 μg l^{-1}	☑
Zinc	68.02 μg l^{-1}	8 μg l^{-1}	☑

Phosphate exceeds the ANZECC trigger by nearly a thousand-fold. Given the ecological impact of phosphorus on periphyton growth in lowland rivers it is very unlikely that the local Regional Council would allow, under the RMA (1991), a resource consent to discharge this to water. However, it is illustrative to explore what this could mean for the size of the grey water footprint for the background system of kiwifruit packaging.

The grey water footprint, WF_{grey}, is found using

$$WF_{grey} = \frac{Effl\,(c_{effl} - c_{nat})}{(c_{max} - c_{nat})}$$

where *Effl* is the volume discharge of effluent at concentration c_{effl}. Here c_{max} is the maximum value allowed, which we take here as the ANZECC trigger value, and c_{nat} is the naturally occurring concentration. For phosphate we take c_{nat} as 10 μg-PO_4 l^{-1}, which is the level reported by MfE (http://www.mfe.govt.nz/publications/water/modelling-water-quality-in-nz-rivers/page9.html) for pristine rivers in the areas governed by West Coast Regional Council, Tasman District Council, and Marlborough District Council. For the wastewater of cardboard the phosphate c_{effl} is 32.95 mg l^{-1} whereas c_{max} is 33 μg l^{-1}. So for a kilogram of cardboard, the WF_{grey} is 750.5 l. Since 0.249 kg of cardboard is used per tray of kiwifruit, this means the grey water footprint of cardboard packaging in the background system is 187 l tray^{-1}, which is a very large number.

Despite WF_{grey} potentially being 187 l tray^{-1} from the background system as a result of cardboard packaging, it is highly unlikely cardboard manufacturers in New Zealand would actually discharge such high-P wastewater directly in surface water bodies. Therefore, we consider it inappropriate to use this value, and will not assign any grey water footprint to the cardboard used in kiwifruit packaging.

The grey water footprints of PET plastic packaging

Todd et al. (1999) state that 1 kg of ‘PET97 Crystalline’ plastic requires 0.68 l of water and results in a polluted water volume, *Effl*, of 0.128 l. We have used here, for consistency these values from Todd et al. (1999), rather than those of Environmental Research (University of Amsterdam) or the Association of Plastic Manufacturers in Europe, who Todd et al. (1999) show have published somewhat different values for the consumptive water use and discharge concentration in PET production.

Again we have chosen a range of contaminants from Todd et al. (1999) to compare with the ANZECC guidelines using the same trigger values as in the cardboard case above.

Table A5.2 Contaminants considered in PET grey water analysis

Contaminant	Concentration	ANZECC Value	Exceedance?
Ammonia	2017 µg l^{-1}	21 µg l^{-1}	☑
Copper	4.09 mg l^{-1}	1.4 µg l^{-1}	☑
Cyanide	149 µg l^{-1}	7 µg l^{-1}	☑
Nitrate	776.19 µg l^{-1}	444 µg l^{-1}	☑
Zinc	25.70 µg l^{-1}	8 µg l^{-1}	☑

All our selected contaminants exceed ANZECC trigger values, and many exceedances are by orders of magnitude. Notable is copper whose exceedance is nearly 3000 times the ANZECC guideline. Given the potent biocidal action of copper, it would be very unlikely that any environmental protection agency would allow a discharge at this concentration to surface water without prior treatment.

It is nonetheless illustrative to examine how this massive exceedance might contribute a background-system grey-water footprint to a tray of kiwifruit through the use of PET in packaging. For copper c_{nat} we can take as zero, for there is unlikely to be naturally occurring levels of copper in most surface water bodies. From the table above we calculate the grey water footprint of a kilogram of PET to be large, 374.3 l kg^{-1}, which on a per weight basis, is about half that resulting from the phosphate emissions in the manufacture of a kilogram of cardboard. However, unlike cardboard, only 1 gram of PET is used in the packaging of a tray of kiwifruit, so the grey water footprint of the PET packaging used for kiwifruit is now just 0.37 l $tray^{-1}$, which is virtually insignificant.

So in this case for PET, but for different reasons than in the case for cardboard, we can again reasonably ignore the grey water footprint from the background system of kiwifruit packaging.

Acknowledgement

The careful assistance of Indika Herath with these calculations is greatly appreciated.

Reference

ANZECC (Australian and New Zealand Environment and Conservation Council) 2000. Australian and New Zealand guidelines for fresh and marine water quality, Chapter 3 (Aquatic Ecosystems). Where published and by whom?

Todd J, Higham R, Grant T, Tabor A, Dimova C, Philpott L 1999. Hardwood and softwood timber production in Australia. Australian Life Cycle Inventory data project. Interim data report. Where published: University of Tasmania and Centre for Design at Royal Melbourne Institute of Technology (RMIT). The report can be downloaded from: http://simapro.rmit.edu.au/LCA/datadownloads.html (last verified 08/06/2010).

Appendix 6 International Peer Review Comments

Safety & Environmental Assurance Centre

Dr. Ivan Muñoz

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1 March 2011

Anthony Hume

Landcare Research

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The terrace, Wellington, New Zealand

Dear Anthony,

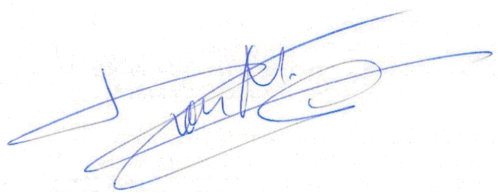
First of all, I would like to express my gratitude to you and Landcare Research for inviting me to review the study "Assessment of the Water Footprint of Fresh Kiwifruit". I have read it with great interest, and although my role is that of a reviewer, I must say I have also used this opportunity to learn new things, since, as shown in the study, water footprinting is a new and rapidly evolving field, where many aspects are yet to be defined, scoped and standardised. This is clearly shown in this work, which has confronted the difficulties in the particular case of tracing kiwifruit from New Zealand orchards to UK households.

Given that currently the Water Footprint standard under discussion in ISO is at an early stage of development, it is not possible to use it in the review as a framework to comply with. As a consequence, I have performed this review not by checking against an existing standard, but rather based on general scientific quality, similarly as when peer-reviewing an article submitted to a scientific journal.

My comments can be found in the following pages. I hope they are useful and contribute to improve, if possible, the quality of this work. I remain at the project team disposal to answer any questions or if further clarity on my comments is required.

I would like to congratulate Landcare Research for the work done, and I encourage the project team to publish the study, or parts of it, in a scientific journal, as in my opinion its quality deserves so.

With kind regards,



Ivan Muñoz

Review of "Assessment of the Water Footprint of Fresh Kiwifruit, Draft Final Report" (dated November 2010)

General comments:

This study reflects the state of the art in terms of water footprint, although as already mentioned in the cover letter, this field is rapidly evolving, and the most recent developments in the area could not be incorporated, such as the guidelines given in the new version of the WFN manual (Hoekstra et al. 2011). It is highly recommended, if feasible, to check changes in this new document that could affect the kiwi study, especially in those areas where the authors claim a lack of clarity in the old manual.

The water footprint of kiwi covers this product from cradle to grave, and yet, the authors are reluctant to add up the numbers in the end, to get an overall figure. This is properly justified based on the insufficient quality of the data available, especially from gate to grave. However, in my opinion it would be useful to at least compare the numbers obtained for the different life cycle stages, either graphically or in a table, in order to summarize the quantitative results and identify actual and potential hotspots.

The analysis is based on two perspectives, namely the hydrological perspective and the consumptive perspective. The latter corresponds to what is commonly understood as water footprint, i.e. consumption of water for provision of a product. The hydrological perspective, on the other hand, rather than focusing on consumed water, constitutes a detailed water balance of the orchard system. While acknowledging the usefulness of this complete balance to achieve an understanding as complete as possible of the system under study, it is my opinion that this approach is not a water footprint; at least, as far as the WFN method is concerned. Concerning ISO 14046, we cannot establish this so clearly, given the early stage of development of this standard. I would recommend using the water footprint term for the consumptive approach, and to use a different one for the hydrological perspective.

I have found in several occasions that the concept of grey water is confused with polluted water. These are different things: a polluted water stream involves a grey water footprint, which is the volume of freshwater needed to assimilate (or dilute) the pollution in that stream.

All these comments as well as other relevant ones are presented in the next section, where references are made to particular pages and sections.

Detailed comments:

- P.15, 2nd paragraph: Grey water does not refer to water rendered unsuitable. This part of the water footprint is not about the polluted water itself, but about the additional water required to dilute (or assimilate in WFN words) that pollution.

The definition of grey water has been clarified to reflect the fact grey water is the additional volume of freshwater required to assimilate (dilute) pollution based on ambient water quality standards.

- Section 4.2: Since the writing of this report new documents of interest have been published, which the authors might be interested in checking, such as the new version of the WFN manual (Hoekstra et al. 2011), and a review article on LCA and water (Berger and Finkbeiner 2010).

The 2011 version of the WFN manual was published after the research in the project was completed. A preliminary check of the latest version indicates the research in this study is still relevant and doesn't require revision or further development beyond the areas highlighted already in the report. Use of the new impact assessment measures included in the 2011 version of the WFN manual is beyond the scope of this research.

Many of the methodologies presented in Berger and Finkbeiner (2010) have been also been discussed in a literature review completed by Matthias Finkbiener in 2009 for the Ministry of Agriculture and Forestry of New Zealand. The choice of WFN and LCA methodology was direct of result of assessment of the information in this document. Within the resources and budget of the project it was only possible to examine the water footprint using two main methods of investigation. The WFN and LCA approach proposed by Milà i Canals et al. (2009) and was chosen as the main methods for further investigation because of their inclusion of green water in the method and the production of relevant published case studies. Later, the Water Stress Index proposed by Pfister et al. (2009) was used to provide further insights to the results. However, it is important to acknowledge there continue to be significant developments in water footprinting methods (even since the completion of this report).

- Section 4.3: I think a diagram showing the supply chain and the system boundaries would be useful.

A diagram showing the green kiwifruit product life cycle (Figure 1) has been added on page 19 in Section 4.3.

- P.16, 2nd paragraph: LCA also accounts for water pollution, although this is not done within the water consumption indicator. Impact categories such as aquatic ecotoxicity or eutrophication cover water pollution.

The text in the 2nd paragraph P.16 has been amended to highlight this point and clarify the treatment of water pollution in LCA by the use of a number of environmental impact indicators including ecotoxicity and eutrophication rather than a single water consumption indicator.

- Page 20, 1st paragraph: section 10 is currently the references section. Which is the section where fruit losses are discussed?

The section number referenced in paragraph (now on p. 21) has been updated with the correct section. Section 9.5 discusses the inclusion of fruit losses during the supply chain and cumulative environmental impacts.

- Page 21, 2nd paragraph: the use of the word 'consumption' here clashes with the terminology defined in section 4.1. Perhaps 'total water abstraction' is more suited.

The use of the word 'consumption' has been removed and replaced by the suggested 'total water abstraction' to clarify the view that LCA databases currently rarely contain data other than total water abstraction in limited cases.

- Section 6.3: It is not clear if some of the packaging materials are used once or reused. For example, in table 11 are some of these materials reused, especially pallets? Or are they entirely allocated to kiwi?

The wooden boxes and pallets are used for the kiwifruit industry in New Zealand and were allocated entirely to green kiwifruit in this study. The figures included in this report are based on data collected for the amount of wooden boxes and pallets in the 2009/2010 (i.e. the replacement of previous wooden boxes and pallets. For the cardboard and plastic bags etc. of trays and boxes containing kiwifruit no recycling was assumed and waste was also accounted for. Wooden boxes are used within the packhouse for up to 15 years and used many times before replacement. Pallets are usually kept and maintained for a number of years or reused by other users when they leave the packhouse facility. Often these items can be considered as capital items with minimal environmental. In future studies reuse wooden boxes and pallets should be considered.

Page 36, 3rd paragraph: why is there a need to split water use between packhouse and coolstore? Is it to separate them in the results? It would be good to clarify this in the text.

A major aim of the overall research project is to investigate the potential reduction options for freshwater consumption in the supply chain. The packhouse and coolstore water use data are separated in this study to help facilitate the discussion of potential options for reduction of freshwater consumption in the different operations. Additional text has been added to the paragraph to highlight this point.

- I don't agree with the deliberate exclusion of water use by staff in the packhouse and coolstore. In the WFN method this is included in the "overhead operational water footprint" (Ercin et al. 2009), and there is no mention of staff water use needing exclusion in this reference. The contribution of this water use to the total is probably very low anyway (actually Ercin and colleagues did not even account for it). However, to me the explanations given in the kiwi study are not satisfactory. I think the overall water use in packhouse-coolstore should be either totally included (accounting for evaporation losses only) or excluded if the authors think this is negligible. If it is included, then subtracting the water use by staff does not make much sense to me. Kiwifruit should be attributed all water use related to its production. If the staff need to have clean hands or go to the toilet during their work time, I think there is no reason why this should not be attributed to kiwi production (especially if these data are available, as it is the case). The authors justify this also using the argument that in LCA labour is excluded. This is true for activities happening outside factories (e.g. workers commuting or having breakfast before work). But activities taking place in the factories are usually taken into account in LCA, if the data are available, for example energy and water use if possible takes into account all activities, rather than allocating them to labour. In my opinion, more often than not, labour (outside factories) is excluded in LCA due to lack of data and because of allocation problems rather than because of lack of relevance. I'm sure in particular cases it might be relevant.

On reflection we agree that the inclusion of the water use by staff would provide a fully picture of water use in the packhouse life cycle stage. All staff water use for the packhouse and coolstore life cycle was attributed to the packhouse operations. This increases the water footprint of the packhouse phase by 0.06 L/TE of Class I green kiwifruit delivered. This equals an increase of 0.3% of the total water footprint of 1 TE of Class I green kiwifruit delivered for the packhouse phase of 18.2 L/TE of Class I green kiwifruit delivered. The text in section 6.4 and throughout the document has been updated. However, the results show that direct water use by packhouse staff in this study is negligible.

- Page 37, 3rd paragraph: again, why is it needed to split the energy used between packhouse and coolstore? Is it to separate them in the results? It would be good to clarify this in the text.

As highlighted above, a major aim of the overall research project is to investigate the potential reduction options for freshwater consumption in the supply chain. The packhouse and coolstore energy use data are separated in this study to help facilitate the discussion of potential options for reduction of freshwater consumption in the different operations. In a small number of cases green kiwifruit could be packed in one location and stored in coolstore in separate location and the results would be useful for reference.

- Section 6.6: what is the source of the energy use, is it the carbon footprint study? Please clarify.

The GHG study completed by Mithraratne et al. (2010) study is the source of the electricity use data for storage of fruit at the port. This has been clarified in the text of the section.

- Section 6.7: What is the source of the fuel use, is it the carbon footprint study? Please clarify.

The GHG completed by the Mithraratne et al. (2010) study is the source of the fuel use data for shipping. This has been clarified in the text of the section.

- Section 6.7: The fuel intensity of shipping seems to be high, when compared with LCA databases like PE International and ecoinvent. According to PE, consumption for ocean bulk commodity carriers is 0.0023 kg fuel/tkm or even lower. Is this ship only carrying kiwifruit? Maybe other cargoes are being omitted in the calculation?

As highlighted above, the work by Mithraratne et al. (2010) was used as the source of fuel intensity data for this study. The data used can be distinguished from the data from PE because the data used are based on the use a refrigerated bulk REFA ship (rather ocean bulk commodity carriers) and also include refrigerant losses. As the water footprint of transport is usually omitted from studies due to the negligible contribution to the water footprint this data wasn't significant to the research completed. The point raised here has been passed to authors of the GHG report for further consideration. It is beyond the scope of this research to reassess the data used in the GHG footprinting study.

- Section 6.11: Are all shoppers assumed to use a car? This would be an overestimate. According to Pretty et al. (2005) only 58% of trips are made by car in the UK, the remaining being by walking, bus or cycling.

It is assumed that all shoppers use a car for the purposes of this study. As highlighted section 6.11, the data are used for illustrative purposes only. This point has been clarified to address the points raised here.

- Section 6.12: Is there evidence to support that kiwifruit is not usually refrigerated at home? In fact I must admit that I keep all my fruit in the fridge.

In this study green kiwifruit is not stored in the fridge at the consumer household. This assumption was made in the GHG study completed by Mithraratne et al. (2010) and was based on discussion with Zespri. Consumer behaviour is difficult to predict and text has been added to section 6.12 to clarify that consumer behaviour is variable.

- Section 6.13: The authors should refer to wastewater generation rather than wastewater consumption, or alternatively to freshwater consumption related to toilets.

An amendment has been added to the text in section 6.13 to clarify wastewater is generated rather than consumed.

- Page 43, last paragraph: The four management scenarios should have been presented in the Scope of the study. However, I have not seen the results of these scenarios in the report. Where they actually assessed?

The four management scenarios were found to make little difference to size of the WFN water footprint and are not discussed in detail in this report. However, the four management scenarios are discussed in more detail in the reduction work completed as part of the overall research (Deurer et al. 2010).

- Page 46: The hydrological perspective is a complete water balance of the orchard. According to the WFN (and probably a very similar definition will be agreed for the ISO working group), "Green water refers to the precipitation on land that does not run off or recharge the groundwater", but in the hydrological perspective both runoff and underground recharge are taken into account. Similarly, blue water in the hydrological perspective is not only about consumptive use, but also about runoff and recharge. In this way, the hydrological perspective moves away from the WFN approach, which is why it is separately presented in the report. However, I challenge the appropriateness of calling this new approach a water footprint, since as mentioned above, it is rather a detailed water balance of the orchard. I think therefore that calling this a water footprint can cause confusion (such as interpreting that kiwifruit cultivation creates water resources) or perverse effects (such as depleting surface waters in order to increase groundwater recharge). The fact that negative values are obtained might convey the wrong message that things are fine, just because the orchard is not using all the water from rainfall and allowing for groundwater recharge. I am sure this balance approach gives very useful insight on how to improve orchard water management, but this approach does not correspond to what up to date is commonly understood by water footprint, which is about consumptive use, i.e. not allowing for negative values. I would therefore not call the result of the hydrological perspective a water footprint.

The green and blue water footprints are deliberately defined differently than the WFN method. The WFN is a non-governmental organization and the method they have devised is not an international standard agreed by the international standards organisation; furthermore, the hydrological approach is provided as an alternative to the WFN method that presents the laws of hydrology, especially mass balance.

The objective of the hydrological perspective was to inform a consumer about the impact of a product on the scarcity (green and blue water footprint) and quality (grey water footprint) of water resources. Water footprinting techniques must be believable and based on sound science. The hydrological perspective based on a water balance approach is better suited in this respect, particularly to water resources management in reduction activity. The hydrological hydrology science community has challenged the definitions of water footprints suggested by the WFN (see for example Perry, 2007). It is important that a discussion of the definition of water footprints is held and hydrologists need to participate.

Perry C 2007. Efficient irrigation: inefficient communication; flawed recommendations. Irrigation and Drainage 56: 367–378.

- Page 55: Instead of unclassified water consumption maybe a more suited term is ‘indirect freshwater consumption’, as it refers to the fact that it is water not directly consumed in the orchard. Also, why these water consumptions were not included in the WFN approach?

Unclassified water consumption has been renamed indirect water consumption in the report. The indirect water uses are not included in the WFN water footprint because it is not possible to determine the proportion of water for each item that is blue, grey or grey water. The data could be included if it is assumed all freshwater consumption for each item is blue water in a worst case scenario, but this approach would only make a relatively small contribution to the water footprint in most regions.

- Page 56, Total WFN water footprint: I am not able to understand the last 4 lines. Could you rewrite please?

The last 4 lines of the text on p. 56 have been revised to clarify the meaning of the comments made.

- Page 61: As the authors realize, applying a characterisation factor at the national level is not useful when all the accounted flows refer to the same country (NZ). Therefore, I think this approach is only useful if the authors decided to compare the scarcity-based impact of processes taking place in NZ (orchard, packhouse, etc.) with those taking place in the UK. As it is now, the method by Milà i Canals and colleagues could be removed from the study as it does not add any value.

The decision to include the method advocated by Milà i Canals and colleagues in the scope of the work was made by the project steering committee. The results have been retained for completeness and to respect the wishes of the steering group who are keen to understand the possible application of the different water footprinting methods discussed.

- Figure 15: FEI stands for Freshwater Ecosystem Impact.

The figure caption has been amended to say 'Freshwater Ecosystem Impact (FEI)'.

- Page 66, 3rd paragraph: if water from electricity production is about 'consumption' then the percentage loss from electricity should not be applied. Do the authors refer to water abstraction instead? Also, what is the source for the 158.76 L/kWh? I have not been able to find it in the appendix.

The source for the total water abstracted in litres per kWh for the average New Zealand electricity mix (158.76) has been added to the text in the section. The text in the section has been corrected so that this figure relates to water abstracted for the generation of electricity but not water necessarily evaporated. The percentage loss is therefore applied to this figure to provide an evaporative loss of freshwater during electricity generation.

- Section 7.5, 2nd paragraph: Shouldn't this paragraph belong to the next section?

The 2nd paragraph in Section 7.5 has been moved to start of Section 7.6.

- Page 68: Green water consumption for cardboard production can be estimated based on a typical consumption by tree growth, and the amount of wood that goes into making cardboard. The latter should be available from the Australian inventory. The green water evaporation by trees, if not available for the Australian case, can be obtained from Gerbens-Leenes et al. (2008) for poplar in 4 countries, ranging from 369 m3/tonne in the Netherlands to 1198 m3/tonne in Zimbabwe. Although Gerbens-Leenes and colleagues do not discriminate between blue and green water, in the case of trees it refers to green only.

The cardboard used for NZ kiwifruit is mainly produced in New Zealand and the wood is sourced from New Zealand. Data on water consumption of trees in Australia should not be used for New Zealand. The climate and soils in New Zealand are fundamentally different to Australia. Also, the wood source for NZ cardboard is mainly trees of the variety *Pinus macrocarpa*, and not poplars. Therefore, the numbers of Gerbens-Leenes cannot be used for our study. Establishing the water balances for the major growing areas of Pinus macrocarpa across New Zealand that would be needed to derive a green and blue water footprint of cardboard was outside the scope of this project.

- Page 69, 1st paragraph: PP and PE were assessed in a water footprint study (Katsoufis 2009), where blue water consumption was estimated as 13.1 and 13.7 L/kg, respectively. These values are substantially lower than the ones estimated in this study, although in the same order of magnitude.

Our results are based on the values of the Australian Life Cycle Inventory. Currently there is no inventory for New Zealand. To our best knowledge the study of Katsoufis focused on India, and the different conditions of production might explain the difference in water footprints compared to Australia.

- Page 70, last paragraph: Why not use the average WSI for NZ instead of the one from Waikato? I assume average WSI values for NZ can be obtained using GIS software by weighting the regional values based on their relative area contribution to the country total.

This proposal has been included in the recommendations as an option for future work on water footprinting in the kiwifruit sector and added to the lessons learned document for consideration by the Ministry of Agriculture and Forestry.

- Page 73, 3rd paragraph: I think the 0.009 figure refers to litres rather than litres/km. See 'Format and typos' section for my comment on units.

The units for the 0.009 figure have been updated.

- Section 8.4: This estimation should be done also for the distribution step, which is probably more important, since although more efficient in terms of payload, the distances involved are higher.

A box discussing the importance of the water footprint for retail distribution activity in the UK has been added to Section 8.4.

- Section 8.6, 2nd paragraph: In the WFN approach, usually grey water is not taken into account when a wastewater flow is treated before discharging to the environment (see Ercin et al. 2009). Given that in the UK, according to Eurostat, almost 100% of the population is connected to wastewater treatment plant, grey water from households could be neglected.

The paragraph in question has been removed and the section has been amended to reflect the work of Ercin et al. 2009. Further references to the wastewater treatment in connection to grey water have been amended to reflect the changes made.

- Page 74, last paragraph: wastewater should be referred to as produced rather than required.

The text of the paragraph has been amended to read '92.64 l of wastewater is produced for each TE consumed'.

- Page 75: If 92.64 L water are used in the household and these have upstream losses of 12.5%, then the household blue water is: [92.64/(1-0.125)] – 92.64 = 13.2 L. Please clarify how the 1.21 L figure is obtained.

Household blue water has been updated to 11.64 l as there had been a mistake in calculation during the research.

- Page 75, last paragraph: see comment above on wastewater treatment.

This paragraph has been removed and the appropriate text inserted recognising the point made about wastewater treatment in connection to grey water.

- Page 76, second paragraph: 'If freshwater consumption is recorded in the database...' Currently consumptive use is not recorded at all. Maybe you could use the term 'abstraction'.

The text in the second paragraph has been clarified by distinguishing between abstraction and freshwater consumption. The fact LCA databases do not capture details of freshwater consumption at the moment has also been highlighted.

- Page 78, 1st paragraph: The WFN method also includes impact assessment (see Chapter 4 in both the old and new manuals) although it does not aim at generating a single number, as opposed to LCA.

The text has been amended to clarify the point raised here.

- Page 84, 2nd paragraph: 'It was not possible... sewage treatment'. I don't understand this sentence. In what sense is this life cycle stage crucial, and what is the role of wastewater treatment here? Also see my previous comment on wastewater treatment and grey water.

The paragraph in question has been amended to improve consistency with previous comments on the role of wastewater treatment. The text highlighting the potential importance of this life cycle stage has been clarified to show that it is less significant than previously understood.

- Page 84, 6th paragraph: Similar as above. If there is wastewater treatment, then grey water is assumed to be zero in the WFN approach. Also, what do the authors refer to when they say 'allocation of freshwater consumption between different food types... in these circumstances'. Is this about freshwater for cooking, for drinking? It is not clear, please clarify.

Wastewater treatment is now treated as zero in the study and the reasons for the omission of grey water clarified. The 'allocation of freshwater consumption freshwater...' referred to the allocation of toilet water between different food types. This point is no longer valid to the context of the discussion and has been removed.

- Page 85, 3rd paragraph: Even if the data quality is far from optimal, I think a graph showing the potential significance (at least in water volumes, maybe also in impacts, using WSI and/or WUPR) of the different life cycle stages would be very useful to get an overall picture. The numbers have been calculated anyway, and presented through the report.

A series of graphs has been added to highlight the importance of different life cycle stages using evaporative blue water loss, the WUPR and WSI to help the reader understand the overall picture of water consumption.

- Section 8.13: Both ISO and WFN take a life cycle perspective in terms of product assessment.

The information in the section now acknowledges the point raised here.

- Page 86, 2nd paragraph: In my opinion the hydrological perspective as used in this study is not part of the WFN method.

The comments about the hydrological perspective have been removed from this section. It is worth noting the hydrological perspective results have been fully separated from the results discussing the WFN method whenever necessary to avoid confusion between the WFN method and the hydrological perspective.

- Appendix 4, Table A.4.1: Does water refer to blue water?

Data in Table A.4.1 includes both blue and grey water because it not possible to separate out blue and grey water estimates in the literature.

- Appendix 5, section A5.1: polluted water is not grey water. So the 48.1 L mentioned are not grey water. The volume required to dilute this volume is actual grey water.

The text has been changed to read polluted water instead of grey water.

- Appendix 5, section A5.1: According to my own calculation, the grey water footprint of cardboard is: 48.1 x (360 – 10) / (33 – 10) = 732 L/kg. However a value of 524 L is presented in the report.

The whole of Appendix 5 has been replaced. This calculation was incorrect and has to be clarified in the updated Appendix 5.

- Appendix 5, section A5.2, first paragraph: as mentioned previously, Effl ≠ grey water. Grey water is the water volume needed to dilute Effl.

The text has been clarified in Appendix 5 to read polluted water volume rather than grey water volume.

- Appendix 5, table A.5.2 and text below: the levels of nitrate and zinc do not exceed the ANZECC thresholds.

The values are now corrected in the table of the revised Appendix 5.

Format and typos:

- The table of contents needs to be updated with headings that are not properly formatted in the report (see additional comments below)
- Many times in the document: water consumption per functional unit is expressed as litres per TE. This is expressed in the report as l TE. It should be instead either l/TE or l TE^{-1}.
- Table 14: the text 'is there a footnote for this' should be removed.
- Page 40: heading needs formatting (post-orchard…)
- Page 62, first line: 'the use' should be removed once.
- Page 76: heading needs formatting (implications…)
- Page 79, First paragraph: unfinished sentence in the last line.

- Page 87: heading needs formatting (Recommendations).

A problem with document template occurred just before the report was sent for International Peer Review. The problem concerned the numbering and formatting of several headings and the listing of headings in the table of contents. These issues were addressed but were not saved in the version sent for review. All the issues listed above have corrected.

References:

- Berger M., Finkbeiner M. 2010. Water footprinting: how to address water use in Life Cycle Assessment? Sustainability 2, 919–944.
- Ercin AE, Aldaya MM, Hoekstra AY 2009. A pilot in corporate water footprint accounting and impact assessment: The water footprint of a sugar-containing carbonated beverage.(Source necessary?)
- Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM 2011. The water footprint assessment manual: setting the global standard. London, Earthscan.
- Katsoufis, INITIALS (2009. Cradle-to-gate water footprint analysis of Borealis Group Polyolefin value chain. MSc thesis, Royal Institute of Technology, Stockholm.
- Pretty JN, Ball AS, Lang T, Morison JIL 2005. Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. Food Policy 30, 1–19.