THE WATER FOOTPRINT OF AGRICULTURAL PRODUCTS IN NEW ZEALAND: THE IMPACT OF PRIMARY PRODUCTION ON WATER RESOURCES

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Indika Kaumudini Herath

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ABSTRACT

Protecting and sustaining global water resources are one of the most challenging issues facing the world. Future food security is threatened by the continued increase in demand for water. Agriculture is, by far, the largest consumer of global freshwater, with irrigation accounting for more than 70% of water withdrawals. As the dominant land use in New Zealand, agriculture has the most widespread impacts on freshwater quality and quantity. The water footprint (WF) is a metric that quantifies the environmental impacts related to water use. The WF is likely to form the basis of eco- verification or environmental product declarations related to water use, thereby communicating water use impacts associated with the production of goods and services to a range of stakeholders, including consumers. While the international standards for water footprinting are still being developed, a number of protocols have already been proposed for quantifying the WFs of a range of agricultural products. If New Zealand is to remain competitive within an increasingly discriminating market place, it will need to be able to demonstrate the impacts of resource use.

The objectives of this thesis are to quantify the impacts of the production of two of New Zealand's economically important agricultural products on water resources. These are wine-grape (*Vitis vinifera*), the top horticultural export product, and potatoes (*Solanum tuberosum*), the largest vegetable crop in terms of area under cultivation in New Zealand. In order to meet this objective, a new method, which is based on a full hydrological assessment, was developed. A further objective is to compare this method with three other WF methods, in relation to their usefulness to stakeholders. This study also aims to identify potential management options, which can be implemented to reduce the water-related impacts of these products.

Electricity is a major input into the supply chains of most primary products and, because hydropower is the major component of New Zealand's electricity mix, it was first decided to determine the WF of hydro-electricity. This WF value of electricity was then used in subsequent assessments of the WF of wine and potatoes. The hydrological water balance method has been used here to quantify the WF of wine production in Marlborough and Gisborne, which are two hydrologically different regions in New

Zealand. This assessment considered approximately 12,600 ha under grapes and 36 wineries across both the regions: and the vineyards were on 29 different soil types spread across 19 climatic regions. The functional unit (FU) is a 750-mL bottle of wine at the winery gate. The hydrological water balance method considers water inflows and outflows into and out of the system and it identifies two main water resources; namely, soil water (the green water resource), and groundwater (the blue water resource). The net uses of these two resources were quantified as the green and blue water WFs. The impact of wine production on water quality, the grey WF, was assessed by considering the average nitrate nitrogen (NO_3-N) concentration and the load of NO_3-N reaching groundwater. Subsequently, the WFs of the same wines were evaluated, by using three other WF methods: the 'consumptive water use method' of the Water Footprint Network (WFN); the stress-weighted WF; and a Life Cycle Assessment (LCA) based method that considers freshwater ecosystem impact and freshwater depletion. All these methods were evaluated for their ability to indicate local impacts on the water resources and their usefulness to key stakeholders. The hydrological water balance method was also used to assess the WF of a potato crop grown in the Manawatu region. This evaluation was supported by field measurements of the soil water content, drainage and leaching of NO_3-N below the root zone. Finally, the WF of a kilogram of potatoes at the packhouse gate was quantified, by using mechanistic modelling, which was robustly supported by these field measurements.

There was large variation in the WF of wine, both within and across the Marlborough and Gisborne regions. This variation reflects the large variability in regional rainfall and the large differences in local soil properties. At the grape-growing stage, the average blue-WFs were -81 L/FU and -415 L/FU for Marlborough and Gisborne, respectively. These negative values indicate that these water resources are being recharged on an annual timescale. The green-WFs were negligible, because the soils are returned to field capacity every year during winter. The average grey-WFs, that is, the water required to dilute the NO_3-N leached in the vineyard phase, were 40 and 188 L/FU for Marlborough and Gisborne, respectively. However, the average concentration of NO_3-N in the leachate was smaller than the New Zealand drinking water standard of 11.3mg /L. The comparison of different WF methods showed that the WFN method for the blue and green footprints does not represent impacts on the local water resources. The ability of the stress-weighted WF and the LCA based method to indicate the local impacts is limited due to the spatial constraints of the characterisation factors that have to be used. The hydrological water-balance method can indicate local impacts on water resources, and it does provide useful information to growers and resource regulators, which will enable them to set measurable targets, in order to reduce the WF.

In the potato study, high spatial and temporal variability in field measurements proved to be very challenging. Therefore, it was considered to be more accurate to account for the whole crop sequence and long term weather data, through mechanistic modelling. The average blue-WF of the potato growing phase was -72 L/kg, thus indicating that the rain-fed potato production system has no deleterious impacts on blue water quantity in the region. This indicates that, for every kilogram of potatoes harvested, 72 litres of water recharges the local aquifer. The average grey-WF was 61 L/kg, of which 56 L/kg is from the cropping phase. The use of the absolute value of the grey WF, in order to understand the impact on water quality, is not straightforward. This point notwithstanding, the average concentrations and loading of NO_3-N from the cultivation phase indicate that current practices are having some impact on water quality. The average concentration of NO_3-N leaching below the root zone was at 11.3 mg /L, which is just at the drinking water standard. The average loading rate of NO_3-N was 27.8 kg /ha/y. The potential to reduce the grey-WF was investigated by modelling three different nitrogen fertiliser application scenarios related to split applications and different timings. All three scenarios reduced the NO_3-N concentrations and loads from the production system. The simulated NO_3-N concentrations were reduced from 11.3 to 9.5 mg /L, and the loading rates were reduced from 27.8 to 24.3kg /ha/y, depending on the scenario. The WF is a useful tool to understand the impact of agricultural systems on water resources and also to derive improvement options. However, the robustness of current WF protocols for quantifying the impact of the product life cycle on water quality is dubious. These methods require further improvements, so that water footprinting can provide reasonable and rational metrics of the sustainable use of our water resources. The research described in this thesis has provided some new steps within this improvement process.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
WF	Water Footprint
LCA	Life Cycle Assessment
WFN	Water Footprint Network
FU	Functional Unit
CF	Characterization Factor
FEI	Freshwater Ecosystem Impact
FD	Freshwater Depletion
ADP	Abiotic Depletion Potential
WSI	Water Stress Index
WTA	Withdrawal to Availability
ET	Evapotranspiration
GIS	Geographic Information System
SPASMO	Soil Plant Atmosphere System Model
TDR	Time Domain Reflectometer