THE WATER FOOTPRINT OF NEW ZEALAND'S FRUIT:
A HYDROLOGICAL METHODOLOGY

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Introduction

Water footprints are touted as indicators of the influence of primary products on water scarcity and water quality. We have developed a hydrological approach to water footprinting that extends the methods developed either by the Water Footprint Network (WFN), or a stress-weighted approach (Ridoutt et al., 2009), or via endpoint modelling (Pfister et al., 2010). We link our footprint to hydrological phenomena in the water cycle.

We first assessed the impact of the generation of hydroelectricity on water availability, and then considered the link between the production of New Zealand kiwifruit and freshwater resource quantity and quality. We have considered hydropower, because electricity consumption is important in the life-cycle of New Zealand's primary products through energy consumption in packhouses and coolstores (Herath et al., 2011). For kiwifruit production we evaluated two approaches for how the green, blue and grey water footprints represented these impacts (Deurer et al., 2011). These issues pose methodological challenges for the footprinters.

Methodology, Results & Discussion

Hydropower: As well as the consumptive-approach of the WFN to the water footprint of hydropower (Gerbens-Leenes et al., 2009; UNFCCC 2009), we have also considered two alternative methods: a net consumptive model (SABMiller-WWF, 2009) and the full net-water balance approach (Herath et al., 2011; Deurer et al., 2011).

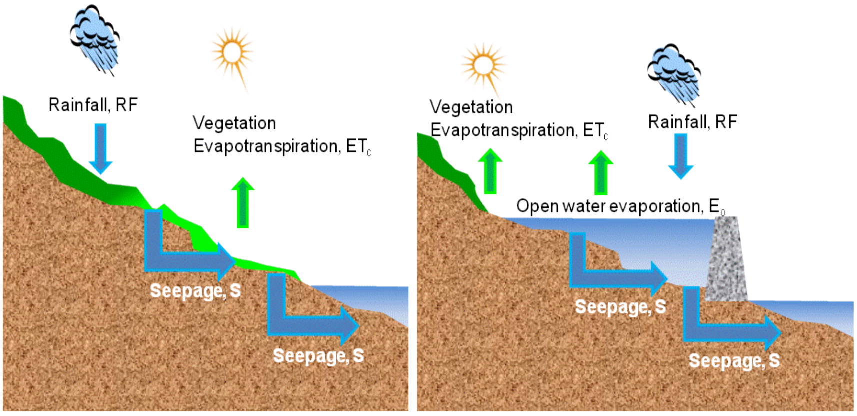

Figure 1. The hydrological components of the water balance prior to construction (left) and after the dam has been built and filled (right) (from Herath et al., 2011).

The WFN approach (Gerbens-Leenes et al., 2009; UNFCCC 2009) is to consider the water footprint as only the evaporative loss of water from the dam E_o ($m^3\ yr^{-1}$) divided by P ($GJ\ yr^{-1}$) the power generated (we designate this to be WF-1). This analysis has yielded a global value of 22 $m^3\ GJ^{-1}$ (Gerbens-Leenes et al., 2009), and a US measure of 18.9 $m^3\ GJ^{-1}$ (UNFCCC 2009). An emissions calculation for the hydropower supply system was found to be 4.7 $m^3\ GJ^{-1}$ for the US (Fthenakis and Kim, 2010), but seems unclear how the water cycle was addressed in this number. A net-consumptive approach, that is the difference in evapotranspiration between the contemporary landscape and that beforehand, was suggested by SABMiller-WWF (2009). For hydropower this would be $(E_o\text{-}ET_c)/P$, where ET_c is the evapotranspiration of the vegetation prior to dam construction (WF-2). We have just developed a full hydrological approach to the water footprint of hydropower by considering rainfall inputs (RF $m^3\ yr^{-1}$) in the calculation: WF-3 = $(E_o\text{-}RF)/P$ (Herath et al., 2011).

For New Zealand we found WF-1 to be 6.05 $m^3\ GJ^{-1}$; WF-2 is 2.72 $m^3\ GJ^{-1}$; and WF-3 is 1.55 $m^3\ GJ^{-1}$ (Herath et al., 2011). Not surprisingly, we consider the latter to be the best metric of the impact of hydropower on the quantity of New Zealand's water resources for it represents better local hydrological phenomena. Thanks to ample rainfall, especially in the North Island and at Manapouri, hydropower generation has little impact on the quantity of our freshwater resources. We caution that this analysis makes no reference to the impact of hydropower generation on riparian ecosystem services, such as the supporting, provisioning, regulating or cultural services flowing from the river system, rather it is simply a metric referenced to water quantity.

Fruit Production: We have also developed a hydrologically based approach to the water footprinting of primary products, such as fruit, that takes into account all the fluxes and storages of water in the rootzone of the trees and vines (Figure 2) (Deurer et al., 2011). In our approach all the footprint water 'colours' can be directly linked to hydrological phenomena, and they differ from those proposed by the WFN. As seen in Figure (2), the soil is the store of both green (rain) and blue (irrigation and frost-fighting) waters. Importantly, we recognise drainage (DR) as a key mechanism for recharge of the blue-water resource of groundwater (Figure 2). The WFN consider it to be 'lost', rather than re-connected within the water cycle.

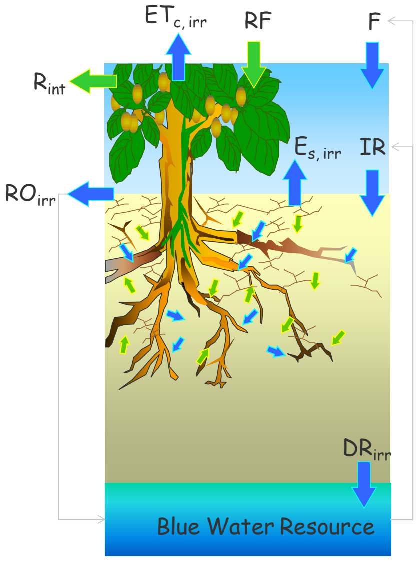

Figure 2. The hydrological components of the full water-balance of kiwifruit, with both irrigation (IR) and frost fighting (F). Drainage (DR) from the rootzone serves to recharge groundwater (Deurer et al., 2011).

We used two measures for the impact on the local hydrology of fruit production: the net change of soil water; and the net groundwater recharge over a yearly timeframe. For the green-water footprint of the soil water store, we found a negligible net annual change in the soil water stock, as by winter's end the freshwater in the soil is replenished (Figure 3), year-on-year, by rain (Deurer et al., 2011). We suggest dispensing with the green water footprint, as the annual change in the soil-water store we consider it represents is invariably small.

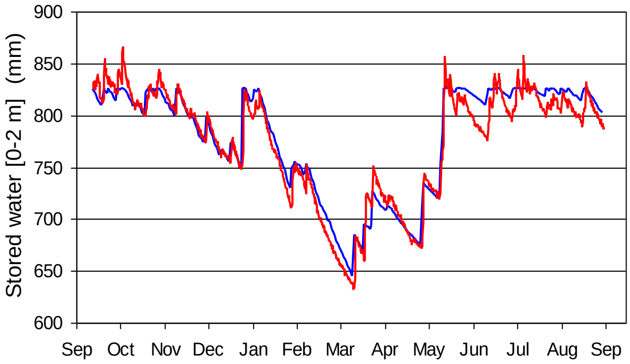

Figure 3. The measured (red) and the SPASMO modelled (blue) storage of water in the rootzone down to 2 m under kiwifruit in the Bay of Plenty.

We tested two approaches to assess the blue-water footprint. In our method, Approach I, the blue water footprint quantifies the net change in groundwater quantity and it describes the influence of kiwifruit growing on the recharge of water to aquifers. This method takes into account all hydrological processes including drainage (DR) as the input to the groundwater. In Approach II of the WFN, only the consumption of the groundwater is considered through irrigation or frost-fighting, while the recharge of the aquifer by rain is neglected, and considered 'lost'. This half-hydrology approach seems to be at odds with the policy and regulatory lament of Glennon (2002) in his book "*Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters*" that "… a complete misunderstanding of hydrology has been memorialized where groundwater and surface water are legally two unrelated things". Hydrology demands they are connected. Policy and management solutions to agricultural water issues therefore also require that they be linked. To be credible therefore, water footprints of products should also rationally recognize connections in the hydrology associated with the production of goods and services.

Therefore we consider Approach I as physically rational, and furthermore the coloured footprints can be related directly to hydrological phenomena. A net depletion of groundwater resources occurs only in two regions (Figure 4). Our blue-water footprint that accounts for DR can thus be linked to the critical hydrological phenomenon groundwater recharge (ΔGW) (Figure 5). It seems that kiwifruit production in New Zealand is, in general, positive in that it has a negative footprint, as demanded by a hydrological assessment of the water balance of the rootzone of kiwifruit. Replenishment of our groundwater resources occurs under kiwifruit. The national yield-weighted blue water footprint is -631(±307) l TE^{-1}, where TE is a tray equivalent of kiwifruit, namely 3.6 kg of fruit. This indicates that over New Zealand's kiwifruit growing regions, rainfall well exceeds evapotranspiration, such that local water resources are, on an annual basis, resupplied and amply recharged. The large variability reflects the variation between regional weather patterns and the impact of different soil types in the regions.

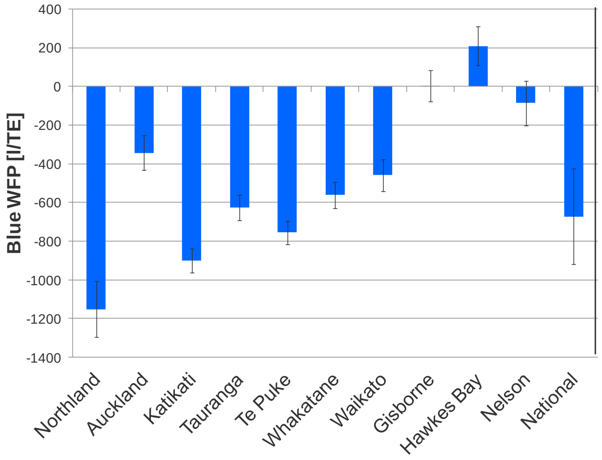

Figure 4. The blue-water footprint of kiwifruit across 10 regions of New Zealand using a full hydrological approach (Deurer et al., 2011). The bars indicate the variability from considering 5 different soils in each region. The footprint units are litres per tray equivalent (3.6 kg fruit): l TE^{-1}.

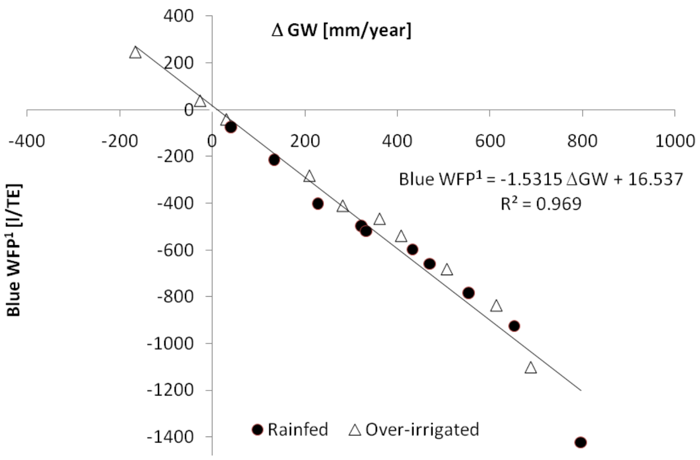

Figure 5. The link between the blue-water footprint of kiwifruit (BWF) and groundwater recharge (ΔGW) showing how a water footprint can be directly linked to a hydrological phenomenon (Deurer et al., 2011).

The grey-water footprint is an indicator of the influence on water quality. Our Approach 1 uses the blue-water footprint to transfer water (DR) of changed quality to subterranean reserves. From this a grey-water footprint can be calculated. The WFN Approach II does not consider DR as a transfer for water quantity. But ironically it does use this unrecognised ‘lost flow’ for the water quality consideration of a grey-water footprint. Irrespective of method, the absolute value of the grey-water footprint is sensitive to the choice of background and maximum guideline concentration value. Considering the natural background concentration of nitrate, and the New Zealand Drinking Water Standard, we find the yield-weighted grey water footprint to 92 (± 62) l TE^{-1}. This is a realistic estimator of the impact on groundwater quality for the prime environmental effect on groundwater would be through its ability to be used as a potable supply of drinking water. If the receiving water body were surface water, then a critical value related to ecological guidelines would be more appropriate. The two values are an order of magnitude different, so care is needed in the selection of the critical value! It must represent the impact that is appropriate for the receiving water body. Whatever, we recommend that the background and critical-limit information must always be given in addition to the grey water footprint value. Further, the large variation again reflects the diversity in the regional weather patterns and the impact of different soil types within, and between regions. Given the great variability in local patterns of hydrology, it appears somewhat meaningless to compute national averages, as the impact of water usage has local impacts. It is similar to the conundrum posed by the curate's egg: good in some parts only!

Conclusions

We conclude that blue-water footprints must be derived by an approach that can be linked to the local hydrology and local impacts. The grey-water footprinting metric for water quality impact, we consider, must also be referenced to hydrological phenomena and appropriate environmental regulations. Because of the footprint definitions we have adopted, the blue and grey-water footprints can be expressed in common units of $l\ TE^{-1}$, namely -631 and 92 respectively for kiwifruit. Yet, we do not advocate their summation, as water quantity and water quality issues, albeit hydrologically linked, are separate issues with respect to policy and management. The sum leaves the total product footprint colour-blind, thereby limiting the vision required to address the complex issues surrounding the impact of primary production of water quantity and water quality.

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