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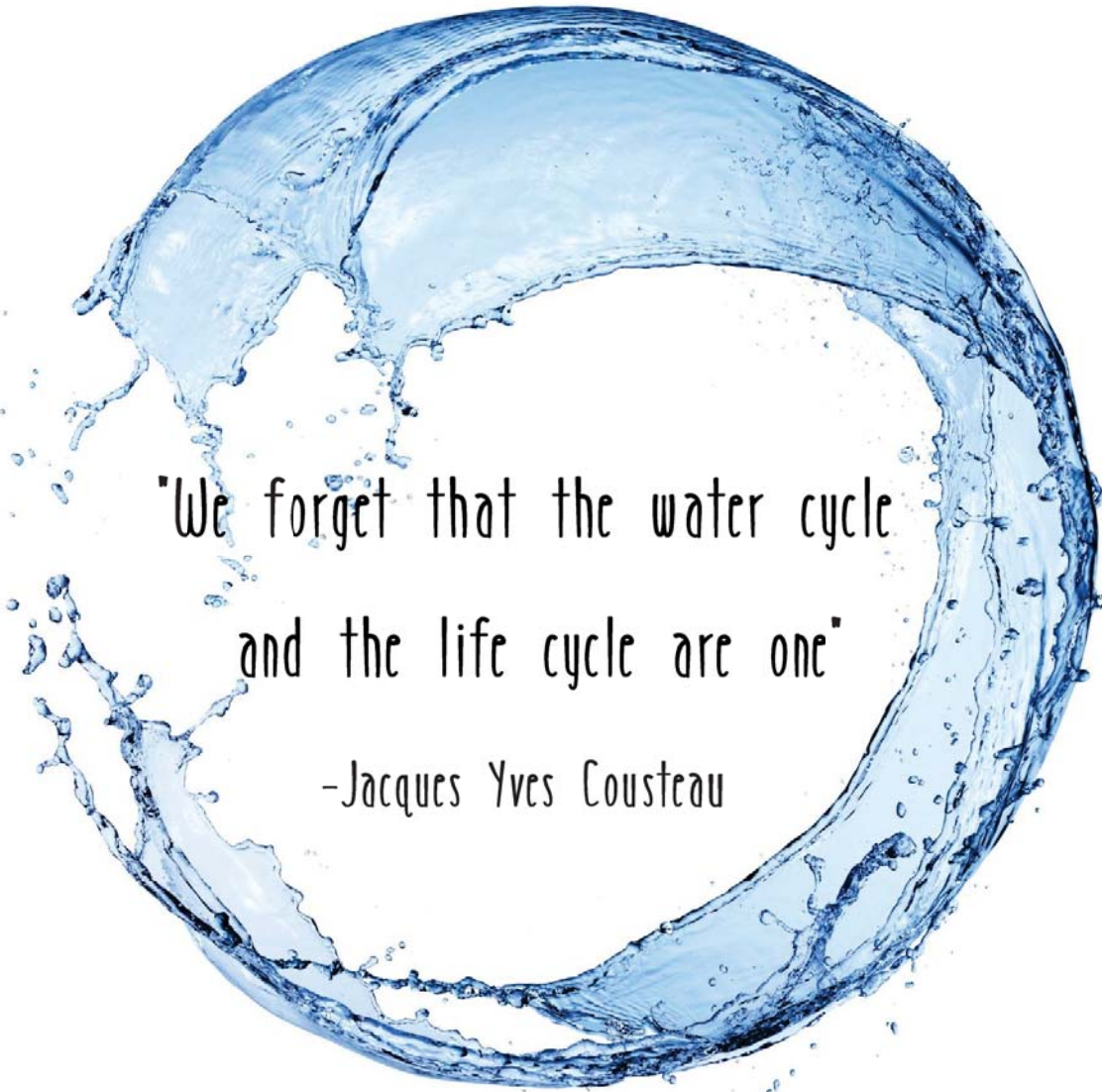
Assessing water footprint and associated water scarcity indicators at
different spatial scales: A case study of concrete manufacture in New
Zealand

A thesis presented
in partial fulfilment of the requirements
for the degree of

Master in Environmental Management
Massey University,
Manawatu Campus, New Zealand

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2017

A circular splash of water, captured in a high-speed photograph, forming a ring. The water is a vibrant blue, and the splash is dynamic, with many small droplets and ripples. The quote is centered within the ring.

"We forget that the water cycle
and the life cycle are one"

-Jacques Yves Cousteau

Abstract

Water scarcity is a growing issue of concern across the globe. In recent times a complex suite of water footprint impact assessment tools and concepts have supplemented traditional management approaches. There are several methods proposed in the literature to both quantify water use and assess its environmental impacts at defined spatial scales. In New Zealand, case studies in the water footprinting space are sparse, and are for the majority focused on the agricultural industry.

This thesis focused on evaluation of different water footprint methods and their associated water scarcity indicators to assess water use impacts for the building and construction sector of New Zealand. The water footprints of 1 m³ ready mix concrete manufactured at 27 concrete batching plants throughout New Zealand were calculated at three distinct spatial scales: the freshwater management zone scale, catchment scale, and regional scale. Four water footprint characterisation factors (blue water scarcity (WS_{blue}) (Hoekstra et al., 2011), water stress index (WSI) (Pfister et al., 2009), water depletion index (WDI) (Berger et al., 2014), and available water minus demand (AMD) (Boulay et al., 2016)) were used to assess the environmental impact of water use for 1 m³ ready mix concrete at the three spatial scales.

The average volumetric blue water footprint of the 27 ready mix batching plants was quantified at 0.18 m³ (180 litres) of water per m³ of concrete, and ranged from 0.15 (150 litres) to 0.29 m³ (290 litres) of freshwater per m³ of concrete. For three of the four water footprint methods used (WDI , WSI and WS_{blue}), and across the three spatial, the Ashburton boundary ranked highest in terms of the environmental impacts of a specified quantity of water use. In contrast, the AMD method ranked the Palmerston North boundary highest across the three spatial scales. At the freshwater management zone and catchment scales, the WDI , WSI and WS_{blue} methods ranked the Wanganui area lowest, and the AMD method ranked the Greymouth area lowest. At the regional scale, all the four water footprint methods ranked the West Coast region lowest in terms of the environmental impact of water use, due mainly to the fact that the West

Coast has more available water and a lower allocation demand than other regions studied. The analysis indicated that volumetric water use varied by a factor of two across the different plants (per m³ concrete). For three of the four WF methods (*WDI*, *WSI* and *WS_{blue}*), the WF results were similar in their rankings of the different plants at all the geographical scales; however, the *AMD* method resulted in different rankings at all the geographical scales. Overall, the *WDI* and *WSI* water scarcity indices calculated by Berger et al. (2014) and Pfister et al. (2009) were less readily adaptable to the finer resolution in New Zealand. The *WS_{blue}* and *AMD* calculated by Hoekstra et al. (2011) and Boulay et al. (2016) however, were found to be more readily adaptable. It is recommended that these methods be explored further with respect to their potential use at the finer resolution in New Zealand.

Acknowledgments

First and foremost, I would like to express my deepest gratitude to my supervisors Dr. Ranvir Singh, A/Professor Sarah McLaren and Dr. David Dowdell for providing me with the opportunity to get involved and contribute in the application and advancement of water footprinting methodology to help assess and improve freshwater use and its management in products and processes. I am especially grateful for their patient guidance, encouragement and the useful critique provided throughout this research process.

I sincerely appreciate and acknowledge the support of the Building Research Levy scholarship, which helped to fund this research project. Similarly, I would also like to thank Mr. Chris Munn of Allied Concrete for partaking in the study and for providing essential data.

My thanks go also to my course coordinator A/Professor John Holland, for his endless enthusiasm for all things in environmental management, and for the much needed humor provided throughout my Masters programme.

My grateful thanks are also extended to the various organizations who provided data and advised throughout this thesis.

Last but not least, I wish to thank my family and friends, both near and far, for their support and encouragement throughout my many years of study. To Dan, I am grateful for your continuous support and encouragement, I couldn't have done it without all your cups of tea.

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List of Abbreviations

Acronym	Definition
EFR	Environmental Water Requirement
LCA	Life Cycle Assessment
WFN	Water Footprint Network
ISO	International Standardisation Organisation
GIS	Geographic Information System
WSI	Water Stress Index
LCIA	Life Cycle Impact Assessment
WAVE	Water Accounting and Vulnerability Evaluation
WTA	Withdrawal-to-Availability Ratio
LCI	Life Cycle Inventory
BIER	Basin Internal Evaporation Recycling Ratio
WDI	Water Depletion Index
CTA	Consumption-to-Availability Ratio
SWS	Surface Water Stocks
WULCA	Water Use Life Cycle Assessment
AWaRe	Available Water Remaining
FMZ	Freshwater Management Unit
SI	Supplementary Information

Glossary of Terms

Water Stress	The ability, or lack thereof, of water to meet human <i>and</i> ecological demands
Water Scarcity	The lack of available freshwater required to meet water usage demands for a particular region
Surface Water	Water that is on the Earth's surface, such as in a stream, river, lake, or reservoir.
Groundwater	Groundwater is the water stored beneath Earth's surface in aquifers (layers of water-bearing rock or sand). Groundwater exists in the zone of saturation, and may be fresh or saline
Blue Water	Refers to the consumption of surface and groundwater resources
Green Water	Refers to the consumption of precipitation on land- insofar as it does not become runoff
Grey Water¹	Refers to pollution, and can be described as the volume of freshwater required to assimilate a pollutant load given natural background conditions and existing ambient water quality standards

¹ Defined according to water footprint terminology