Indices of the status of freshwater resources for impact analyses

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Abstract
The sustainability of fresh-water use is increasingly becoming a topic of global concern. Adequate clean water is a fundamental necessity for human and ecological health. Indicators can be used to evaluate the vulnerability of freshwater systems. This paper reviews three freshwater indicators and their advantages and limitations. Simple indicators like the Falkenmark Index and the Water Scarcity Index are easy to use, but fail to delineate accurately a comprehensive picture of freshwater availability. In contrast, the Water Poverty Index covers wider aspects of freshwater availability and use. However, its complexity limits discrimination in international comparisons. The utility of indices depend on how well they assess the water demand and supply of a country. It is understood that it is important to account for the water transferred due to traded goods. None of the indices considered here take this into account. The water footprint concept is based on consumption of water use which helps accounts for water traded in virtual form. The sustainability of water use depends upon the impact of water use and this varies spatially and temporally. The water footprint can be referenced to water resource indices for a better understanding of the impact of water use. For international comparisons to be valid they need to take into account the localized impact of water use. According to considered indicators of water availability, New Zealand is well endowed with freshwater resources compare to Australia, USA and Sri Lanka, but its high levels of water use reveal the need for vigilance to protect the country's valuable and renewable water resources.

Key Words
Freshwater, indicators, impact, water footprint.

Introduction
Globally, issues related to the quantity and quality of freshwater are becoming as important as those associated with greenhouse gas emissions (Clothier *et al.* 2009). Water is a complex resource: it cycles in a dynamic fashion between rainfall and irrigation, runoff and drainage, storage in the soil profile plus transpiration and evaporation, all with enormous temporal and spatial variation. In addition, variation in water quantity and quality governs its value to people and ecosystems (Rijsberman 2005). Across the planet, water supplies are unevenly distributed among and within countries. A range of water related indices have been developed to measure, track and evaluate the state and vulnerability of water systems, and to assess the impact of water use. It is important to understand the actual water use in a country and its impact on the sustainability of fresh- water resources. The utility of an indicator depends on how well it captures the use and availability of water in a country. The objective of this paper is to review three freshwater related indicators which vary in complexity and content, and to discuss New Zealand's fresh water status in relation to those indicators.

The Falkenmark Index
The Falkenmark Index is defined as the amount of water available in a country per capita (Gleick *et al.* 2002). Falkenmark *et al.* (1989), as cited by Rijsberman (2005) a threshold value of 17,000 m^3 renewable water resources per capita per year is proposed. Countries whose renewable water supplies cannot sustain this figure are said to experience water stress. When supply falls below 1000 m^3 per capita per year, a country is said to experience 'water scarcity', and below 500 m^3 per capita per year, 'absolute scarcity'. The Falkenmark Index has been widely used (Gleick *et al.* 2002) as it is very straight forward to calculate and easy to interpret. However, this indicator has a number of shortcomings. It assumes that water availability is constant over time and so does not account for the fluctuations in water availability on a seasonal basis. This index also assumes that water availability is evenly distributed within a country, thereby hiding inequalities in regional availability. Finally, simple threshold values do not reflect important variations in the demand for water in different countries due to, for instance, climate, lifestyle, and economic factors.

The Water Scarcity Index
The Water Scarcity Index for a country is calculated as the annual water use expressed as a percentage of the available water (Hoekstra and Hung 2002). In this index, the available water is given by the precipitation falling within the country's borders. According to Hoekstra and Hung (2002), total water use should ideally refer to the sum of 'blue' water (the amount of water withdrawn from ground or surface water) and 'green water' (the amount of water evaporated and transpired from plants that comes from rain water). But for the water scarcity values presented in Table 1, only blue water use has been accounted for. This index is simple and easy to understand, but it also fails to accurately delineate a comprehensive picture of water scarcity. Water withdrawals do not take into account how much of it is 'consumptively' used. Ecological water requirements are not considered; and neither is the quality of the water.

The Water Poverty Index (WPI)
The Water Poverty Index is an attempt to develop a comprehensive index of water well-being (Lawrence *et al.* 2002). Gleick *et al.* (2002) showed various approaches which can be used in calculating the WPI. Lawrence *et al.* (2002) pointed out the link between "water poverty" and "income poverty" and used a holistic approach to calculate WPI. This index clusters around five sub-indices: resources; access; capacity; use; and environmental aspects. The 'resources' component includes internal water resources and external water inflows. The 'access' sub- index includes the population with access to safe water and sanitation, irrigation water for crops, and water for non-agricultural use. 'Capacity' covers socio-economic aspects which includes income to allow purchase of treated water, plus education and health. The 'use' component accounts for domestic, agricultural and non-agricultural water use (Lawrence *et al.* 2002). As stated above, the WPI indicator has the advantage of being comprehensive. But it is complex to calculate and is not intuitive. This is nonetheless a common problem with comprehensive indicators. Sullivan (2002) presented ways in which an interdisciplinary approach can be taken to produce an integrated assessment of water stress and scarcity. It illustrates the importance of including ecological water requirements plus geo-referencing the various WPI variables in the calculation (Sullivan 2002).

Any method used to assess the water demand and availability of a country needs to consider the comprehensiveness, complexity and the utility of the various indices. Most of the water availability indicators use total water withdrawal within a country as the water demand. This ignores the water that enters and leaves the country in the virtual form due to the traded goods and services between nations. Virtual water is defined as the volume of water required to produce a commodity or service (Hoekstra and Chapagain 2007). Virtual water content covers three components: blue, green and grey water use. Water footprinting looks at the overall water required to produce a given product or meet a specific demand, whether national or personal. The water footprint of a nation is defined as the total volume of freshwater that is used to produce the goods and services consumed by the people of the nation(Hoekstra and Chapagain 2007), and it will be an inevitable part of a metric of water sustainability.

However, the quantification of water use and trade by water volume alone is only a partial guide to environmental impact and to the sustainability of water use. The economic and the environmental impacts of water use vary from region to region, and season to season as do water supply and demand. Therefore, indices need to take into account the localized impact of water use for the international comparisons to be valid.

Status of fresh water resources in New Zealand
New Zealand is a country with abundant national water resources and a relatively small population density. This is made evident by comparing the values for the Falkenmark and WSI Indices for New Zealand with Australia, USA and Sri Lanka (Table 1).

When considering the water poverty index (WPI), it is evident that there is a loss in discrimination between countries, because of countervailing values of the sub-indices. For example, due to very high domestic consumption of water, New Zealand has a very low value (of just above zero) in the 'use' sub-index of the WPI (Lawrence *et al.* 2002). According to Lawrence *et al.* (2002), New Zealanders used 653 liters of water a day per capita for domestic purposes. This rates as "excess use" and compromises the overall New Zealand value for the WPI.

Table1. New Zealand's water indices compared to some selected countries.

Indicator	Country and Value		Reference
Falkenmark Index		(Thousands of	(Lawrence *et al.* 2002)
	New Zealand	m^3)	
	Australia	102.8	
	Sri Lanka	18.2	
	USA	2.7	
		8.9	
Water Scarcity Index	New Zealand	0.6	(Hoekstra and Hung 2002)
	Australia	8.0	
	Sri Lanka	24.1	
	USA	19.9	
Water Poverty Index	New Zealand	69.1	(Lawrence *et al.* 2002)
	Australia	62.3	
	Sri Lanka	56.2	
	USA	65.0	

Why New Zealand needs to pay attention on water use and productivity?

Given the values for the indicators reported in Table 1, one could argue that there are few risks to the quantity of water resources in New Zealand. But we demonstrate the importance of increasing water productivity especially, agriculture in New Zealand. New Zealand is in the top three in the world list of net virtual water exporters with respect to the livestock products. The net export volume for the period of 1995-1999 was 20.4 Gm^3/yr (Chapagain and Hoekstra 2003). The virtual water content of some of New Zealand's livestock products is very high. For example, it is claimed that the milk produced in NZ has a virtual water content of 1909 m^3/ton which is more than double that of the world average value of 820 m^3/ton (Chapagain and Hoekstra 2003).

International sustainability standards for water are currently being developed. New Zealand, as a major virtual water exporter, will increasingly need to show that its use of water is sustainable. In addition, the labels for promoting sustainable water use and communicating this to consumers are being developed. The stated sustainability of water use might well be reflected in the premium price of the final product. When international crop-trade related virtual water flow is considered, New Zealand shows a 30% virtual water import dependency (Hoekstra and Hung 2002). The major water use in New Zealand is by agriculture and irrigation. Intensification has led to a rise in the amount of irrigation, with a near doubling in the past twenty years (Davie 2009). It is predicted that it could double again in the next 20 years. As fresh water resources are finite, increasing demand will eventually be limited by supply unless significant efficiencies can be found.

Conclusion

Indicators related to water resource availability vary in content and complexity. Simple indicators like the Falkenmark Index and the Water Scarcity Index are easy to use, but they do not provide a clear picture of the fresh-water status of nations. On the other hand, the Water Poverty Index covers wider aspects of freshwater status, including environmental aspects which most of the other indicators fail to consider. However, its complexity limits discrimination in international comparisons. The utility of indices depends on how well they assess water demand and water supply of a country. The water footprint concept brings in a consumption-based indication of water use as it accounts for water traded in virtual form. The sustainability of water use depends upon the impact of water use. For the international comparisons to be valid it needs to take into account the localized impact of water use. According to key indicators, New Zealand is well endowed with fresh water resources. But our high levels of water use show that there is a need for vigilance to protect our valuable and renewable water resources.

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