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Virtual water: a case study of green beans and flowers exported to the UK from Africa

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Glossary

Blue & green water	Blue and green water refers to two different states of water within the hydrological cycle. Blue water is the water found in rivers, lakes, reservoirs, ponds and aquifers. It therefore accounts for all water used in irrigation. Green water is essentially rainfall and also the return flow of water to the atmosphere as evapotranspiration from water bodies such as lakes and ponds. Green water is described as 'productive' if transpired by crops and natural vegetation, or 'non-productive' if evaporated from soil and open water. Two-thirds of water in the hydrological cycle is green water.
Covered systems	Types of agricultural systems that require some kind of plastic or glass cover for growth i.e. greenhouses or smaller hoop styled plastic houses.
Crop water requirement	The total water needed for evapotranspiration from planting to harvest for a given crop in a specific climatic regime when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield.
Dilution water	Refers to a theoretical amount of water needed to dilute waste flows to such extent that the quality of the water would remain above agreed water quality standards. Dilution water can further be assessed based on the character of the return flows whether it is from point source (processing industries) or non-point (return flows from farm land).
Drip irrigation	A system of tubes with small holes that allow water to drip out onto the root zone of plants. This is generally considered the most water-conserving irrigation system.
Non-vvaporative	This is water that has been applied to the field but has not been transpired by the crop. It could also be called irrigation 'losses'.
Virtual water	The virtual water content of a product is the volume of water used to produce a product, measured at the place where the product was actually produced. The adjective 'virtual' refers to the fact that most of the water used in production is not visible in the end product. The real water content of products is generally negligible if compared to the virtual water content. This study uses the evaporative virtual water content (EVWC) of green beans and flowers. This is just the amount of water transpired by the crop to reach harvest.
Water footprint	A measure of the total water requirement of products consumed by a particular individual, business or nation.
Water import dependency	Countries with import of virtual water depend, de facto, on the water resources available in other parts of the world. The virtual water import dependency of a country or region is defined as the ratio of the

	external water footprint of the country or region to its total water footprint.
Water scarcity	Water scarcity has often been defined as the ratio of actual water withdrawals to the available renewable water resources. This is currently a supply-oriented definition and does not express scarcity from a demand perspective.
Water self-sufficiency	This is the ratio of the internal water footprint to the total water footprint of a country or region. It denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self-sufficiency is 100 per cent if all the water needed is available and indeed taken from within the own territory. Water self-sufficiency approaches zero if the demand for goods and services in a country is largely met with virtual water imports.

1. Background

The trade and environment debate now includes issues of freshwater utilisation as part of future economic development and livelihood strategies in many developing countries. The challenge is to assist development strategies that depend on significant amounts of freshwater not only to be beneficial and equitable for users, but also to be sustainable for the environment and local livelihoods in the long term. We believe that specific on-site studies of the virtual water contents of crops can improve our understanding of the trade-offs surrounding this challenge.

In a recent DfID white paper, ’Eliminating world poverty: making governance work for the poor', a need for ‘ensuring that growth is based on sustainable use of natural resources, given rising worldwide consumption and threat of climate change' is expressed. A subsequent section on 'using natural resources for sustainable growth' mentions the concept of 'natural capital' being disproportionately important in developing countries (DfID, 2006: 66). The UK is pledged to 'with international partners, help countries to make efficient use of natural resources, especially water and energy' and 'reduce the impact of UK consumption production and procurement on the global environment'. In Hilary Benn’s own introduction to the paper, he states that 'the scarcity of resources and climate change could stop development in its tracks. Yet on the other hand, there is the uncomfortable realisation that development, if not managed well, can itself make resources more scarce. The challenge then is to make sure that development is sustainable and also fair' (DfID, 2006). It is within this context that this paper has been commissioned.

This short study focuses on one particular aspect of global food trade assessing the significance of the virtual water trade for selected fresh products imported to the UK from African countries. Here we focus on two products, green beans and flowers, that are emblematic of a trade and development debate uniting Southern producers and Northern markets. The virtual water discussion given here provides the foundations of the virtual water concept and gives added context to this debate. Previous studies focusing on the crop water requirements of various crops under different growing regimes (Hoekstra and Hung, 2002; Yang and Zehnder, 2002; Chapagain and Hoekstra, 2003*b*; 2003*a*; Mori, 2003; Oki et al., 2003; Yang et al., 2003) allow for opportunities to both explore water amounts owing to traded product and analyse impacts of growing in specific areas. It is crucial that localised impacts from growing crops for export are understood to provide context to the water quantity and quality data and issues that embedded water studies can provide.

2. Freshwater in context

To date, research involving food traded from distant sources has focused almost exclusively on the finite nature of fossil fuels and the way in which transport emissions can be expected to engender significant climate change (Boge, 1993: Raven & Lang, 1995: Jones, 2001: Pirog et al, 2001: Pretty et al, 2005: DEFRA, 2005). Globally, 70 per cent of all freshwater is used in agriculture, arguably making water the most critical component of food production. Despite this fact, discussions on critical water issues have been noticeably absent from this food and trade debate. With growing population pressure coupled with the necessary intensification of agricultural activity under projected climate change scenarios, and the resultant strain on freshwater environments worldwide, research needs to be undertaken on the sustainability of water use for all types of food production.

Unsustainable use of freshwater resources has economic, environmental and social causes and impacts. The withdrawal of groundwater at rates greater than nature's ability to renew it is widely documented in many parts of the Middle East, India, Mexico, China, the former Soviet Union and the United States (e.g. Falkenmark & Lannerstad, 2003; UN, 2006). The high-profile example of wasteful over-abstraction in Central Asia for irrigated cotton and wheat production has involved almost the entire flow of the Amu Darya and Syr Darya Rivers (Glantz, 2005) and has become a symbol of what can go wrong when trans-boundary water is mismanaged. The water used for producing export commodities can be significant and contribute to changes in regional water systems. While reduced river flows, depleted groundwater aquifers, and deteriorating water quality are resulting in significant adverse ecological and social impacts, freshwater shortages for domestic and productive means are threatening to check economic growth and poverty reduction efforts.

In most arid and semi-arid regions, water availability, access to water resources and water for meeting basic human needs is a daily struggle. It is predicted that by 2025 two-thirds of the world's population will live in water-stressed areas if present trends continue (UNEP, 2000). Today 1.1 billion people are without access to safe drinking water and 2.6 billion lack sanitation (UNESCO, 2003), perhaps indicating failure on the part of development efforts to address basic human needs (UN, 2006). Future water managers must calculate how to provide for this shortfall amid unprecedented water demand. A complicating factor is that 95per cent of future populations will be born into already infrastructurally-poor and ill-funded communities

The daily drinking water needs of people vary between 3 to 9 litres depending upon climatic conditions, totalling between 1,000 litres and 3,000 litres of clean water per capita per year. Water for personal and domestic hygiene purposes is considered satisfactory by the World Health Organization if it is at a minimum of 30-50 litres per day. More realistically, an average of 9 litres of water is available for the poorest and up to between 150 to 350 litres per capita per day for those with western lifestyles and flushing toilets (Waterwise, 2006). If the amount of water for growing the food that people consume is included, then these numbers increase significantly. It is estimated that 1,000 m^3 (1 million litres) to 1,300 m^3 per capita/yr is required to meet minimum standards in food production (Zehnder et al, 2003), giving a more realistic picture of the minimum water 'footprint' that each individual is responsible for.

Globally, 60 per cent of the world's accessible freshwater supply is found in just nine countries, illustrating water's uneven distribution across the globe (WBCSD, 2005)[1]. Of all freshwater, 79 per cent is found in glaciers and the ice caps, 20 per cent is found as groundwater and 1 per cent is accessible as surface freshwater. Of the accessible water, 52 per cent is lake water and 38 per cent is soil moisture, with 1 per cent each to rivers and water in organisms. The total amount of freshwater

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[1] These are Brazil, Russia, China, Canada, Indonesia, U.S, India, Colombia and the Democratic Republic of Congo.

is estimated to be 39,200,000 km^3 (USGS, 2006) and exists in two distinct but constantly interchanging states: green and blue water.

The concept of green water was introduced to better understand the role of water in agricultural production in sub-humid and semi-arid areas (Falkenmark, 1995). Green water is essentially rainfall and is described as ‘productive’ if transpired by crops and natural vegetation, or ‘non-productive’ if evaporated from soil and open water. This non-productive aspect of the water cycle has also been termed ‘white’ water (Ringersma et al, 2003). Blue water is the water found in rivers, lakes, reservoirs, ponds and aquifers**.** All water used for irrigation purposes is therefore blue water which also gives higher yields than rain-fed agriculture because of the ability to regulate its application at the field level. Currently, 16 per cent of global crop land is irrigated, producing 40 per cent of all food. This makes irrigated crop land about 3.6 times more productive per unit-area than non-irrigated crop land (Crosson, 1997).

3. Virtual water

There is no easy fix to the future water scarcity issues discussed in the previous section. To meet societal needs while protecting the life-support system upon which social and economic development depends (Falkenmark, 2003), requires efforts on many fronts. Virtual water studies are one tool among many to help provide that vital link between water, food, and trade (Allan, 2003*a*). The positions at which policy can be applied, or how management and procurement decisions can be informed, may not yet be clearly defined. But few would argue that actually knowing how much water is being consumed by agriculture, where that water comes from, what aspects of the hydrological system are involved, what pollution effect is left at the growing site and in the context of the area grown, is not desirable.

The rest of the report lays out the foundations of this concept, its applicability to understanding water's involvement in trade, and a review of previous studies and criticisms of this concept. This study focuses on a minor part of crop trade in order to hone in on considerations of virtual water trade. DfID is rightly exploring the full environmental impacts of trade promoted on the grounds of international development. They recognise that for development gains to be worthwhile and long term, the resource base on which trade depends cannot be degraded to levels that hamper livelihoods and economic growth in producer countries.

3.1 Definition

Virtual water is the total green and blue water used in the production of a crop or the processes of a given product (SIWI, 2005). It is sometimes described as 'embedded' water (Allan, 1998). This report focuses on the virtual water content of green beans and flowers from Africa.

In an effort to understand why often predicted water wars for the Middle East region had not materialised[2], Prof. Tony Allan conceptualised this idea of water in trade. Conflicts over water, he suggests, are mitigated by the trading of water-intensive foodstuffs, relieving pressure on insufficient national and regional water endowments. According to Allan, the Middle East and North Africa (MENA) region ran out of water in 1972, when the region's total population reached 122 million. Since then the region has withdrawn more water from its rivers and aquifers every year than is being replenished. For many countries in the region, wheat is a staple food among the poor. Yet the water needed to produce wheat for such large populations is either not physically present, would be too wasteful to produce in an economic and resource sense, or would involve diverting water from other sectors. For this reason many countries opt to rely on international grain markets to provide food and water security. At present Jordan imports 91 per cent of its grain, Israel 87 per cent, Libya 85 per cent, Saudi Arabia 50 per cent and Egypt 40 per cent (Worldwatch, 1999).

Allan soon discovered that virtual water theory was extremely provocative amongst economists and engineers. 'The former argued that it was confusing to suggest that water was being traded in the process of moving water intensive commodities, such as grain, from one place to another. It is not water that is being traded; it is food…Engineers generally felt the idea was fanciful' (Allan, 2003*a*:5). There is a great deal at stake with a concept which draws attention to where a country's water security actually lies. Making links between water and food security is a high-profile issue, with associated risks, and presents a potentially high political price for water policy makers (ibid). There are necessary trade-offs to be made between efficiency in water terms and the political

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[2] Conflicts over water do occur, but they are much more likely to take place between user groups within societies, than between countries. Allan was referring to state conflicts as suggested by Joyce Starr (1991) in 'Water Wars'.

imperative of maintaining livelihoods, social stability, food security and rural employment in many nations (Chapagain & Hoekstra, 2003). Political and economic considerations sometimes overshadow global water scarcity concerns and hamper the potential of trade as a policy tool to mitigate water scarcity (de Fraiture et al, 2004).

An examination of responses to criticism has thrown up examples of cases where the concept has been used to formulate national trade policies, such as in the MENA region. Allan points out four major virtues of virtual water. First, it is very effective in addressing water deficits. Second, it is economically invisible. Third, it is politically silent. Finally, it can be mobilised in a much more condensed form across time and space than any other engineering solutions. While virtual water theory has it critics, the debate over virtual water's usefulness should not detract from quantification studies which seek to establish exact water use in food trade and link consumption to production sites where export oriented agriculture is adversely impacting freshwater resources.

Each year the UK imports a significant number of 'luxury' items, such as unseasonal foods (tomatoes, green beans, etc), exotic products (fruits, nuts, flowers) and stimulants (coffee, tea) for consumption. These products are not generally discussed in virtual water studies but are at the centre of trade debates from developing countries. The relative impacts of these products are determined by the area where they are grown, the source of and amount of water used, the individual crop water requirements, pollution effects at the growing site and any relative situations of scarcity or equity among users. In order to establish links to consumers and retailers, quantifying water content of the various processes involved in production are needed.

3. 2 Virtual water content

To quantify the scale of water in trade, the example of wheat is often used. It roughly takes 1,000m^3 of water to produce a tonne of wheat. If a country imports 1 million tonnes of wheat then it is said to be 'virtually' importing 1 billion m^3 (1 km^3) of water (Allan, 1999). In essence, the export of a tonne of grain to a political economy short of freshwater would spare that nation the economic, political and environmental stress of mobilising 1,000 m^3 of water (Allan, 2003*a*). For rice, another water intensive crop, the ratio of 1 kg rice to 2 m^3 of water is used. One of the largest water-consumptive products is beef fed with supplemental feed such as soy, which requires 15-16,000 litres of water to produce 1 kg of meat (Hoekstra, 2003).

The following table highlights water-intensive cereal products which make up a significant part of global food trade.

Table 1: Selected cereal crops

Crop	Global production (tonne/yr)	Global water consumption ($10^6 m^3$/yr)	Average virtual water content (m^3/tonne)	Share in global water consumption for crop production
Wheat	594,594,467	792,917	1,334	12.4%
Rice, Paddy	593,173,644	1,358,732	2,291	21.3%
Barley	139,624,574	193,760	1,388	3.0%
Maize	603,140,262	548,387	909	8.6%
Rye	22,039,337	19,866	901	0.3%
Oats	27,315,146	43,616	1,597	0.7%
Millet	28,078,732	129,057	4,596	2.0%
Sorghum	59,471,080	169,660	2,853	2.7%

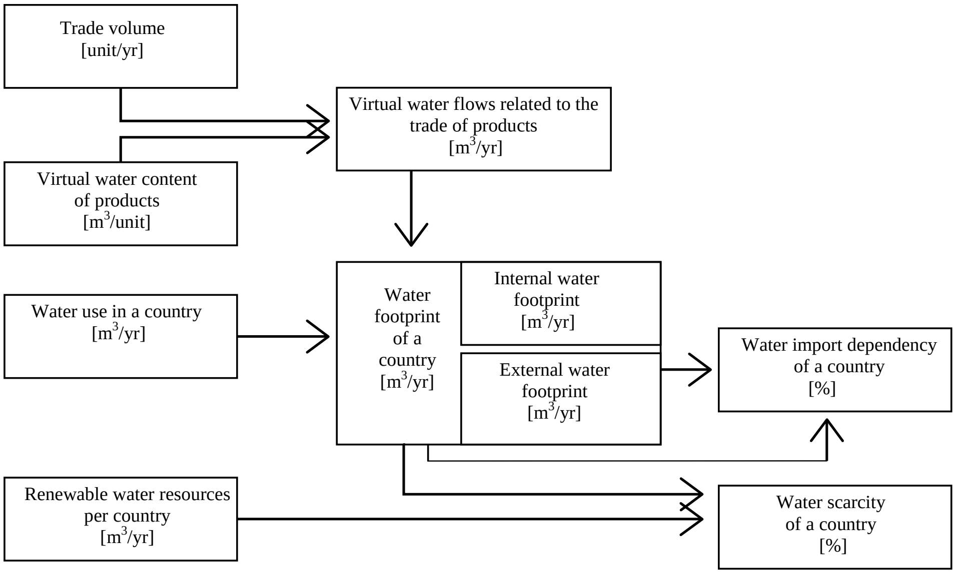
Source*:* Chapagain & Hoekstra (2003)

Many water scarcity, food security and virtual water trade studies have been published, with a few estimating the scale of virtual water embodied in the global food trade (Hoekstra & Hung, 2002: Oki et al, 2002: Zimmer & Renault, 2002). Hoekstra and Hung (2002) quantified virtual water flows between nations and established that crop-related water trade was 695 Gm^3/year[3] on average over the period 1995 to1999. The global water withdrawal for agriculture was about 2,500 km^3 average over that time period. Taking into account the use of rainwater in crops as well, the total use by crops in the world has been estimated at 5,400 km^3/year (Merrett et al, 2003). Later studies established that 336 Gm^3/yr of virtual water was traded in livestock and livestock products during the same period (Chapagain & Hoekstra, 2003). During the period 1997 to 2001, the virtual water content of all international trade in livestock, crop and industrial products has been estimated at 1,625 Gm^3/year (Chapagain & Hoekstra, 2004). This study showed that 16 per cent of water used in world crop production is not for domestic consumption, but for export (Chapagain et al, 2005*a*).

Virtual water studies have highlighted food security benefits for regions such as Southern Africa (Turton, 1999; Jobson, 1999; Earle, 2001), and Palestine (Nassar, 2003), as well as food trade in Japan (Oki et al, 1999). The relative comparative advantages of countries have been used to explain why virtual water trade takes place (Wichelns, 2001; Renault, 2003; Allan, 1997; Greenaway et al, 1995). Virtual water has been used to explain changing diets (van Hofwegen & Zimmer, 2003), and is particularly important for modernisation contexts such as China, where rapid industrialisation, urbanisation and affluence are affecting the imports of foodstuffs to a historically self-sufficient region. Rosegrant and Ringler (1998) have researched expanding domestic and industrial sectors in agrarian societies. With water as a limiting factor in food production, studies have focused analysis on higher returns for investment or ‘crop-per-drop’ (Renault & Wallender, 2000: Postel, 1996: GWSP, 2005); an approach which is also being highlighted in reports from global development agencies and industry (FAO, 2003; Rabobank, 2002; WBCSD, 2006).

The quantification of water across a number of products can provide a water ‘footprint’. Figure 1 presents a framework for establishing footprints, import dependencies and new considerations for water scarcity.

Figure 1: Framework for establishing water footprints



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[3] This paper uses both Gm^3 and Km^3 (depending upon authors) to represent 1 billion m^3.

Water footprints are another way to look at a nation's dependence on foreign water resources and to establish the real water demand of a country from a consumption position. While similar to ecological footprints (Wackernagel & Rees, 1995) in name, water footprints represent real water resources as opposed to theoretical global hectares. The water dependency of the UK has been determined through another study (WWF, 2006). This is the dependence on external water resources defined as the ratio of the external to the total water footprint. The UK relies on the water resources of other countries for 74 per cent of our consumption. The water self-sufficiency is defined as the ratio of the internal to the total water footprint, and is therefore 26 per cent.

The concept of water scarcity was developed by Falkenmark (1995) to reflect the relative water resources available within countries per population. With a wider understanding of water's involvement in trade, there is an opportunity to conceive scarcity from a different perspective. More specifically, water scarcity was originally defined as the ratio of actual water withdrawals to the available renewable water resources. This supply-oriented definition is useful from a production perspective, but does not express the scarcity from a demand perspective. Water scarcity can also be defined as the ratio of the total water footprint of a country or region to the total renewable water resources. The national water scarcity can be more than 100 per cent if a nation consumes more water than domestically available (see table 2, Egypt and Jordan).

The external water footprint of a country refers to the use of water resources in other countries to produce commodities imported into and consumed within the country. Although a number of countries e.g. Kuwait, Qatar, Saudi Arabia, Bahrain, Jordan, Israel, Oman and Lebanon, combine very high water scarcity with very high water import dependency, the relationship between water scarcity and water import dependency is not wholly accounted for by a simple equation. While the water footprints of these countries have largely been externalised, the rates of scarcity to dependency can vary greatly. Some countries have high water scarcity but low water import dependency. Yemen, for example, overdraws from limited groundwater resources. Yemen has a low water import dependency for the simple reason that it does not have the foreign currency to import water-intensive commodities in order to save domestic water resources. They have to make do with less water in general. Egypt, on the other hand, combines high water scarcity and low water import dependency intentionally, aiming at consuming Nile water to achieve food self-sufficiency (Chapagain, 2006).

The water scarcity and use of external water resources for some selected countries are presented in Table 2. India has a very high national self-sufficiency ratio (98 per cent), which implies that at present India has low dependence on the import of virtual water from other countries to meet its national demands. The same is true for China, with a self-sufficiency ratio of 93 per cent. However, India and China have relatively low water footprints per capita (India 980 m^3/cap/yr and China 702 m^3/cap/yr). If the consumption pattern in these countries were to change to that of the US or some Western European countries, they would face water scarcity in the future. Water self-sufficiency would have to be compromised, which while perhaps not an obvious problem, would draw enormous populations into the sphere of virtual water trade.

Table 2: Water scarcity and water import dependency for some selected countries (1997-2001)

Country	Total renewable water resources[1] (Gm^3/yr)	Internal water footprint[2] (Gm^3/yr)	External water footprint[2] (Gm^3/yr)	Total water footprint[2] (Gm^3/yr)	Water scarcity (%)	National water self-sufficiency (%)	Water import dependency (%)
Argentina	814	48	3	52	6	94	6
Australia	492	22	5	27	5	82	8
Bangladesh	1,211	112	4	117	10	97	3
Brazil	8,233	216	18	234	3	92	8
Canada	2,902	50	13	63	2	80	20
China	2,897	826	57	883	30	93	7
Egypt	58	56	13	70	119	81	19
France	204	69	41	110	54	63	37
Germany	154	60	67	127	82	47	53
India	1,897	971	16	987	52	98	2
Indonesia	2,838	242	28	270	10	90	10
Italy	191	66	69	135	70	49	51
Japan	430	52	94	146	34	36	64
Jordan	0.9	1.7	4.6	6.3	713	27	73
Korea Rep.	70	21	34	55	79	38	62
Mexico	457	98	42	140	31	70	30
Netherlands	91	4	16	19	21	18	82
Pakistan	223	157	9	166	75	95	5
Russia	4,507	229	42	271	6	84	16
South Africa	50	31	9	40	79	78	22
Spain	112	60	34	94	84	64	36
Thailand	410	123	11	135	33	92	8
UK	147	22	51	73	50	30	70
USA	3,609	566	130	696	23	81	19

[1] FAO (2003)
[2] Chapagain & Hoekstra (2004)

The quantification of the water content of crops can also be linked to consumers through individual products or a number of products from one area or country. It can be argued that within globalised food economies people in Japan now indirectly affect the hydrological system in the United States or that people in the UK indirectly impact on the regional water systems of Kenya. The international trade in agricultural and industrial commodities creates a direct link between the demand for water-intensive commodities (notably crops) in most countries and production sites in others. If the impacts are negatively affecting freshwater resources in the growing site, then there are opportunities to highlight how products from certain areas are directly linked to specific sites. Opportunities also exist to work with retailers and growers in working to reduce and arrest impacts at the growing site towards more sustainable practices.

4. Methods

For this report, we have calculated blue and green evaporative virtual water content (EVWC), non-evaporative virtual water content and dilution volumes for flowers and green beans, specific to their growing site. The evaporative content is the amount of water that has transpired through crop growth. Any additional water applied to the crop but not transpired is considered non-evaporative or irrigation loss. Green water content is the part of the evaporative demand of the crop met from rainfall while blue water is the part of evaporative demand met from supplied irrigation water. For the examples used here, the EVWC is almost entirely blue. This is because these systems are generally covered throughout the entire length of the crop growth meaning that water needs are secured entirely from irrigation water. The following schematic diagrams (Fig 2-5) show the steps required to obtain the water content of any given crop.

The virtual water content of a crop (m^3/tonne) is calculated as the ratio of the total volume of water used for crop production (m^3/ha), to the total volume of crop produced (tonne/ha).

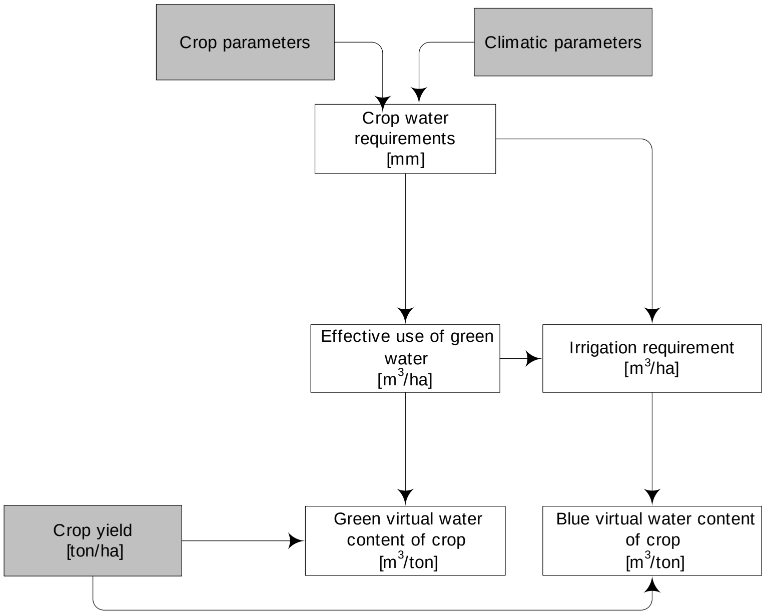
$$V = \frac{U}{Y} \tag{1}$$

The volume of water use, U is calculated per hectare of land using the CROPWAT model from FAO. It gives the crop water requirements for a given crop in the specified climatic region. The calculation of CWR in CROPWAT uses the Penman-Monteith equation to estimate evaporation, and then using appropriate crop coefficients, gives reference evapotranspiration in mm per day. Together with the respective growing period (days) it gives the total crop water requirements (CWR) in mm per period of crop growth (Figure 2).

With the selection of representative rainfall stations, one can immediately obtain the effective rainfall amounts that are available during the crop growth period. Finally, it also gives data on irrigation requirements for the chosen time interval. The difference between total crop water requirement and the irrigation requirement is the use of green water. The total effective rainfall available during the entire crop period might be higher than the ‘green water use’ for crop production as the temporal availability affects the irrigation requirement. Assuming that the irrigation requirements are fully met, the blue water evaporated from crop land would be equal to the irrigation water supply minus the losses at the field level.

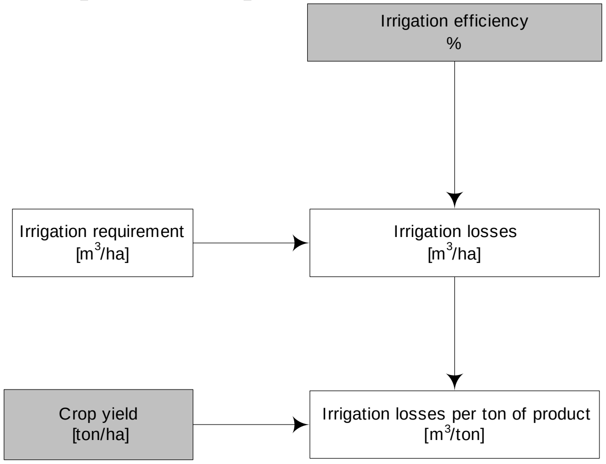
With crop production per unit area (yield in tonne per hectare), the blue and green virtual water content of the crop is calculated as shown in Figure 2.

Figure 2: Steps to calculate the evaporative virtual water content (EVWC) of a crop



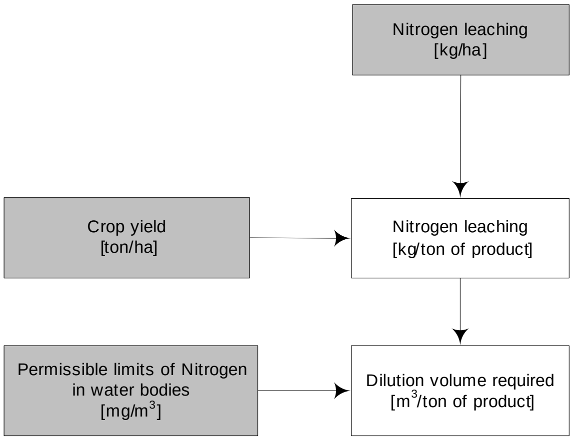
The blue water supplied at the field level is always higher than what has evaporated from the crop as a result of irrigation inefficiencies. With the existing irrigation efficiencies, one can calculate the volumes of water being lost as a result of crop production. Dividing the irrigation losses by the crop yield, we get the *non-evaporative virtual water content* of the crop. This is also expressed in cubic metres of water per tonne of product as shown in Figure 3.

Figure 3: Steps to calculate the non-evaporative virtual water content of a crop (irrigation losses per tonne of product)



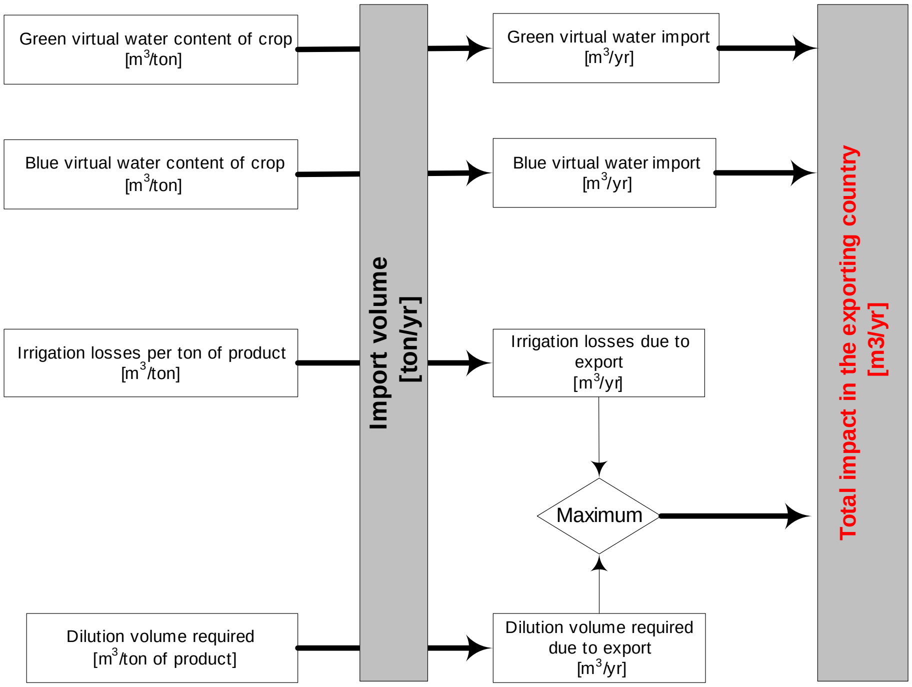
The effect of pollution is measured in terms of dilution volume of water necessary per tonne of final crop from the field. Based on the agreed permissible limit of pollutants in the free flowing surface water or ground water bodies, one can estimate the volume of water necessary to dilute the return flows to the permissible limits. In our case, we have taken nitrogen as the major pollutant from the crop field that leaches into the water bodies as a result of inefficiency in fertiliser uses in farms. Figure 4 shows the steps to calculate the dilution volume per tonne of crop products.

Figure 4: Steps to calculate the dilution volume of water necessary per tonne of crop production.



The virtual water content of green beans and flowers are calculated based on crop water requirements and yields. Crop water requirements were calculated per crop and per country in CROPWAT using the methodology developed by FAO (Allen et al., 1998). When combined with trade data from the Personal Computer Trade Analysis System of the International Trade Centre (PC-TAS), which covers trade data from 146 reporting countries by disaggregated product and partner countries (ITC, 2005), the trade in virtual water can be calculated. The total impact on the water resources of exporting countries is the sum of 'green virtual water import', 'blue virtual water import' and the maximum of irrigation losses or dilution volumes necessary as a result of crop production for export (Figure 5).

Figure 5: Steps in calculating the impact of import on the water resources of exporting countries.



4.1 Flowers

The UK imports 170,267 tonnes of cut flowers worth US $1,551,703 (cut flowers and flower buds for bouquets or ornamental purposes) annually. Of this amount, the import share from African countries is 7 per cent by quantity. The largest African exporter to the UK is Kenya with a 90 per cent share of the total African flower export during the period 2000 to 2004 (ITC, 2004). The major cut flower producing regions in Kenya are Naivasha and Thika (Hughes, 2001).

Roses and carnations are the principal traded cut flower products. In 1995, world rose imports accounted for 23 per cent of all flower imports, carnations had a 15 per cent market share, followed by chrysanthemums at 9.5 per cent. Between them, roses, carnations and chrysanthemums make up close to 50 per cent of global cut flower trade.

4.2 Green beans

The virtual water content of green beans is calculated for Kenya, Egypt, Zambia and Spain, which contribute nearly 82 per cent of the total export of this crop to the UK. Imports from other African countries are calculated using the share export volume from these four major countries to the UK. The virtual water content of beans in each season is calculated for these four countries, for the major producing regions in each country and seasonal values are weighed on the basis of production from each season. Similarly, regional numbers are weighed on their share to the total national production.

We calculated green bean planting as an average from 1st September in the first season with the total crop length of 75 days. The second season starts from 1st February and takes 90 days before it reaches harvest. Irrigation efficiencies for greenhouse production systems are assumed to be 80 per cent, whereas for open systems they are assumed to be 40 per cent in all four countries. Covered systems contribute to 80 per cent of the production in the season starting 1st September, whereas there is only 50 per cent contribution from the second season. We have used national average yields (tonne/ha) to calculate the virtual water content of green beans irrespective of any temporal or spatial variations.

5. Results

5.1 Flowers[4]

In Kenya, the crop water requirement of rose plants in Naivasha is 830 mm/yr and 1000 mm/yr in Thika. With the average yield of rose plants in Kenya (66 tonne/ha), the average virtual water content of Kenyan roses is 90 m^3/tonne. As the drainage from the rose farm is about 66 per cent, the non-evaporative virtual water content of covered roses from Kenya is 190m^3/tonne. However, theoretically the use of hydroponics systems could reduce this component to zero. Assuming the nitrogen leaching rate from rose fields is equal to 145 kg/ha and the permissible limits of nitrogen in free flowing surface water bodies are equal to 50 mg/litre, then the dilution component of the virtual water content of roses is equal to 44 m^3/tonne. Recycling nutrients could theoretically reduce this number to zero.

Table 3: Virtual water import of flowers (m^3/yr) to the UK from selected African countries (using the average VWC values from Kenya) (2000-2004)

Exporter	Blue water evaporated	Green water evaporated	Non-evaporative (irrigation losses)	Dilution volume required
Cameroon	886	522	2,423	562
Cote d’Ivoire	817	481	2,234	518
Ethiopia	291	171	795	185
Kenya	810,133	477,374	2,216,120	514,398
Morocco	46,420	27,353	126,982	29,475
South Africa	18,380	10,830	50,278	11,670
Tanzania	443	261	1,212	281
Uganda	6,090	3,588	16,658	3,867
Zambia	4,498	2,650	12,304	2,856
Zimbabwe	15,570	9,175	42,592	9,886
Total	903,526	532,406	2,471,597	573,699

National weighted average virtual water content of rose flowers is calculated based on the share of each region to the total aerial coverage of rose farms in Kenya. The CROPWAT model is used to calculate the crop water requirements, effective use of green, water and the irrigation requirements. Later, these numbers are adjusted to greenhouse conditions by multiplying by 0.65 to accommodate relative water efficiency within covered systems as suggested by various authors (see Mpusia, 2006; Fernandes et al, 2003; Harmato et al, 2004). We have estimated the national average virtual water contents of flowers based on the weighted average of the indoor and outdoor farm area to the total area under cultivation. However, as the numbers are aggregated over time and space a larger more detailed study would flesh out any discrepancies arising from such assumptions.

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[4] In this study the virtual water content of all the cut flowers imported into the UK has been estimated as equal to the average of the virtual water content of roses and carnations from Kenya. The different crop parameters for rose and carnations in Naivasha are taken as: Start of green-up date: 1st October; Start of harvesting period: 1st December and the remaining period of the year. Crop coefficients for different growing stages are taken as equivalent citrus with 70 per cent ground cover from Allen et al. (1998). The crop lengths are adjusted accordingly; e.g. for the first harvest the crop water requirement of the rose plant is calculated as 30 days for the initial stage, 30 days development stage, 260 days mid stage, and 45 for the late stage.

We have included this 'pollution effect', water losses from the field as a result of irrigation inefficiencies, and the climatic variations in different producing regions. The pollution effect is accounted for based on the permissible limits of nitrogen in free flowing water bodies, measured at 50mg/litre. The evaporative demand of the crop is assumed to be satisfied by supplementary irrigation in all cases. Again, this report is establishing virtual water content as evaporative virtual water content, or only that water which has been transpired during the plant growth.

Table 4: UK import of flowers from the world (using the average VWC values from Kenya)

	Virtual water import (10^6 m^3/yr)		
	Total import	Import from Kenya	Share of Kenya
Blue water evaporated	11.8	0.8	
Green water evaporated	6.9	0.5	7 per cent
Non-evaporative (irrigation losses)	32.2	2.2	
Dilution volume required	7.5	0.51	

Every year the UK imports 19 x 10^6 m^3 of water from all over the world as a result of flower import (assuming the global average virtual water content of roses is similar to Kenya). The import of cut flowers to the UK results in evaporating 1.3 x 10^6 m^3 of water resources, resulting in the pollution of 0.6 x 10^6 m^3 of Kenyan blue water resources and an inefficient use of irrigation water supplies equal to the volume of 2.2 x 10^6 m^3 Table 4). Dilution water volumes are included and represent a theoretical amount of water that would be needed to dilute chemicals applied to the field for production.

5.2 Green beans

Every year the UK uses 189 x 10^6 m^3 of African water as a result of the import of green beans Table 7). The import of green beans to the UK results in evaporating 93 x 10^6 m^3 of blue water and 28 x 10^6 m^3 of green water. If we assume that the use of fertiliser results in the leaching of 145 kg of nitrogen per hectare of farm land, then imports to the UK pollute 160 x 10^6 m^3 of African water resources. However, as a result of irrigation inefficiencies, part of this requirement is already satisfied through the non-evaporative virtual water import of 67 x 10^6 m^3 per year. As we do not have reliable data regarding the leaching of fertilisers from bean farms, we have not included the polluted return flows in the calculation of total virtual water import into the UK from Africa. More information would be required to include this into future studies.

Table 5: Virtual water content of green beans (m^3/tonne) in major African exporters and Spain to the UK (2000-2004)

	Product import (tonne/yr)	% share of total	Virtual water content of green beans (m^3/tonne)			
			Evaporative			Non-evaporative
			Green	Blue	Total	
Kenya	77,954	0.70	1,295	3,320	4,614	2,253
Egypt	14,168	0.13	0	3,517	3,517	3,218
Zambia	11,812	0.11	958	4,936	5,894	3,729
Spain	8,217	0.07	198	1,008	1,206	799
Total	112,151		1,015	3,345	4,361	2,424

The product fraction presented in Table 6 (see Chapagain and Hoekstra, 2004) of dried beans is assumed to be 0.4. The virtual water content of dried beans is calculated by dividing the virtual water content of green beans by this fraction.

Table 6: Virtual water content of dried beans (m^3/tonne) from major African exporters and Spain to the UK (2000-2004)

	Product fraction	Virtual water content of dried beans (m^3/tonne)			
		Evaporative			Non-evaporative
		Green	Blue	Total	
Kenya	0.4	3,237	8,299	11,536	5,631
Egypt	0.4	0	8,792	8,792	8,044
Zambia	0.4	2,395	12,339	14,734	9,323
Spain	0.4	495	2,521	3,016	1,998
Weighted average		2,538	8,364	10,902	6,059

Table 7: Virtual water import (10^{6}m^3/yr) to the UK related to the import of green beans from selected African countries (2000-2004)

	Evaporative virtual water import (10^6 m^3/yr)			Non-evaporative virtual water import (10^6 m^3/yr)	Total impact (Excluding the effect of pollution) (10^6 m^3/yr)
	Green water	Blue water	Total evaporative		
Egypt	0.00	9.97	9.97	9.12	19.08
Ethiopia	0.24	0.79	1.03	0.57	1.60
Gambia	0.65	2.15	2.80	1.55	4.35
Ghana	0.03	0.08	0.11	0.06	0.17
Kenya	20.19	51.76	71.94	35.12	107.06
Madagascar	0.24	0.79	1.03	0.57	1.60
Malawi	0.16	0.54	0.71	0.39	1.10
Morocco	1.74	5.72	7.46	4.15	11.61
Nigeria	0.04	0.15	0.19	0.11	0.30
South Africa	0.27	0.90	1.17	0.65	1.82
Spain	0.33	1.69	2.02	1.34	3.35
Tanzania	0.28	0.91	1.18	0.66	1.84
Uganda	0.05	0.18	0.24	0.13	0.37
Zambia	2.26	11.66	13.92	8.81	22.73
Zimbabwe	1.73	5.71	7.45	4.14	11.59
Grand total	28.22	92.99	121.21	67.36	188.57

In total the consumption of Kenyan beans and roses to the UK accounts for evaporating 73 million m^3 of water, the largest part of which is from blue water resources.

More detailed studies could compare the water used through export crop production with the water bodies used for irrigation. In this context these numbers may be insignificant or substantial depending on the fluctuations, increases or decreases in these water supplies. This is where virtual water studies can provide added value to other work. To say anything about this we need to know more about the relative in situ water issues and water management policies.

Further studies would also consider the net water loss/gain after the water embedded in Kenyan imports is factored in, and compare water efficiency between production systems in the developed and developing world.

6. Discussion and recommendations

Strategies for managing trade, in an ideal world, take into account its cost. Rather than being considered a by-product of trade, virtual water could be seen as a part of a series of measurements that inform us as to the environmental impacts in given regions. It would be hard to say as yet whether trade patterns could be altered to account for environmental impact, or which nations, rich or poor, might sign up for such recognition.

When consumers buy a Kenyan rose, do they consider the 2.7 litres of blue water that was evaporated for its production or that this polluted 1.3 litres of water resources in Kenya? Do they consider how much water a Dutch rose uses? Does the price of a particular rose stem represent its impact on the water resources in the place where it was grown? Can the existing market bring the demand and supply to an equilibrium at which the price truly reflects the opportunity cost of the use of water resources for a particular rose stem?

From a social and economic view, horticulture and floriculture exports from emerging markets such as Zambia and Kenya have been praised as positive moves toward cash crop production (IFPRI, 2003; Minot & Ngigi, 2004; Wichelns, 1999). From an environmental perspective, the depletion of water levels and deterioration of water quality in places like Lake Naivasha are blamed on this export-led trade (Pearce, 2006; Harper, 2005). Proponents of these differing positions are bound to clash. What is clear, however, is that these positions can no longer be treated in isolation. Development gains are essential, but when poverty alleviation strategies require large amounts of freshwater for production, then it is necessary that both ends of this debate spectrum see the benefits of better resource base monitoring. If the use of water for export is exacting high costs for local livelihoods and the environment, then it may be strategically important to adopt policies that can offset any unregulated industry.

Emotive press accounts have highlighted the issue of water use from one of the production sites in this report, Lake Naivasha. One states that ‘Naivasha is being sacrificed because we require too much water. Almost everybody in Europe who has eaten Kenyan beans or Kenyan strawberries or gazed at Kenyan roses has bought Naivasha water. It is sucking the lake dry’ (Harper, 2006, quoted in *The Independent*). This and other press accounts point out the issues in a rather polarised way, but also show how virtual water is interpreted in the media. Kenya will face severe water scarcity in the future, yet this is not to say that water from Kenya cannot be extracted and distributed in a beneficial way. It is hoped that Kenya’s dilemma will elicit urgent action to move resource-base issues into development debates.

From a policy position, there are a number of levels on which this information can be helpful. Can there be a way to influence retailers’ protocols? It is clear that the supermarkets are increasingly concerned about their public image and consumers are demanding to know that there is at least some effort being made to address environmental issues of food trade. As consumers are becoming more enlightened towards wider issues, they are becoming inundated with a range of ethical choices: fair-trade, organic, seasonal, local, food /air miles. Can we now expect them to take on virtual water, or do they expect government and business to tackle this for them?

One of the areas in which the concept of virtual water offers potential for significantly improved policy analysis is in understanding where and to whom the rents from water use accrue. Where scarce water resources are allocated to productive use at prices below the marginal value, potential rents exist. These may not be captured locally, but will be further up the supply chain, or through increased consumer surplus. Tracking virtual water enables us to analyse rents more clearly.

In Mexico, for example, export trade has increased to the US market since the NAFTA treaty came into force in 1994. Fodder crops are exported from Mexico to the US beef industry. There is also a significant horticulture export industry. Water is free for irrigation in Mexico, and there are no water scarcity signals to alert growers to the depletion of Mexico's largest Lake, Lake Chapala, where levels have dropped by 15 per cent since 1994. This drop is directly due to abstraction designed to generate virtual water exports (van Hofwegen, 2004: Pearce, 2006). The rents available from water use in Mexico may therefore be being captured by consumers and producers in the US, essentially making virtual water an environmental subsidy from Mexico to the US.

Obviously, any real impacts on water resources from the countries in this study cannot be captured alone with the two products discussed in this report. Larger, more detailed studies need to assess the complete picture of trade from this region. There is a general consensus that water issues are of crucial importance worldwide (UN, 2006; IWMI, 2006) and therefore a number of practical solutions and policy pathways must be explored. Virtual water studies do have an important role to play in wider environmental studies and should be supported to achieve a better knowledge base about the freshwater resources on which agricultural trade depends. This paper supports a number of existing water management recommendations and additional suggestions for future virtual water study.

How can the government help exporting countries to monitor their water usage and make trade more efficient and sustainable for the long term?

- Differentiate the blue and green inputs into crops. Build capacity for green water to be utilised better or better captured for crop growth.
- Promote more benign irrigation practices and help increase irrigation efficiencies.
- Reduce chemical applications that have the potential to leach into the surrounding freshwater systems.
- Place an upper limit on basin extraction and share equitably and transparently.
- Launch educational campaigns encouraging an understanding of the real value of water to all basin inhabitants.
- Provide baseline information to poorly-understood production sites i.e. groundwater resources and use, downstream user needs, environmental flows etc.
- Establish the real state of water resources in export countries to feed directly into development plans. A clearer understanding of the opportunity costs of water needs to be developed.
- Establish future water scenarios for countries affected by climate change and population increase, which include water exports and imports through trade.
- Feed development gains (taxes) back into water infrastructure projects.

Policy engagement

- Help and support local and national government bodies to achieve these aims.
- Influence stricter guidelines under retailer protocols e.g EUREP-GAP.
- Work with CSR departments. Supermarkets' concern over their image will increase approachability. How far will supermarkets be willing to accept their impact and be ready to work with growers?
- Provide guidelines for helping buyers to maintain sustainable supply chains.
- Help provide advice and information for catchment-level user groups and manage water resources for long-term benefits.

What VW studies and research might be useful in terms of future policy?

- More detailed micro studies. Full trade and export studies across nations and regions. Virtual water studies in context (with full estimation of in situ water resources, availability, equity, etc)
- Wider national studies to include access, equity, rents, export and opportunity costs.
- Develop baselines for the environmental flows of freshwater river systems to maintain high levels of natural capital and help reduce and arrest freshwater biodiversity loss.
- Establish the impacts of degraded environments on livelihood strategies so that these negative impacts may be anticipated.
- Determine catchment-level impacts from export firms and view how they might be regulated to maintain healthy trade and sufficient freshwater.
- Do we need some global protocol on using natural resources?

It is important that policy takes due account of the need to manage change constructively. Introducing policies that would seriously impact on this trade in the short term would of course do considerable harm to those workers involved in the industry. Government can play a role in encouraging managed conversion to more sustainable production of more appropriate products, such that production can continue to benefit communities while reducing associated environmental impacts.

The globalisation of freshwater brings both risks and opportunities. The largest risks are that the indirect effects of consumption are externalised to other countries. When production sites are mismanaged, it becomes imperative for all stakeholders involved to ensure that development gains in the short term are not made at the expense of significant long-term environmental benefits. If in Africa, for example, freshwater resources are degraded to unsatisfactory levels, short-term benefits could soon dissipate, while long-term damage could prove difficult or impossible to overhaul.

Opportunities arise when gains can be made that take freshwater environments into consideration, and policies to promote agricultural expansion account for the wider picture. Vigilant monitoring of freshwater environments is needed to ensure that this is the case. Water is still priced far below its real cost in most countries, and an increasing volume of water is used for producing export products. This presents real but achievable challenges tomorrow for Northern policy makers: but only if they are willing to take these issues on board today.

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