Hoekstra, A.Y. (2012) Water footprint accounting, In: Godfrey, J.M. and Chalmers, K. (eds.) Water accounting: International approaches to policy and decision-making, Edward Elgar, Cheltenham, UK, pp. 58-75.

3. Water Footprint Accounting

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INTRODUCTION

Freshwater is a global resource as a result of international trade in water-intensive goods such as crop and animal products, natural fibres and bio-energy. The use of water resources has, to a great extent, become spatially disconnected from the consumers. Using cotton as an example, from field to final product cotton passes through a number of distinct production stages with different impacts on water resources. These stages of production are often located in different places with final consumption in yet another place. Malaysia does not grow cotton, but imports raw cotton from China, India and Pakistan for processing in the textile industry and exports cotton clothes to the European market (Chapagain et al. 2006). As a result, the impacts of consumption of a final cotton product on the globe's water resources can only be identified by looking at the supply chain and tracing the origins of the product.

The aim of Water Footprint Accounting is to quantify and locate the water footprint of a process, product, producer or consumer or to quantify in space and time the water footprint in a specified geographic area. Uncovering the links between consumption and water use can inform water governance strategies by identifying new triggers for change. Where final consumers, retailers, food industries and traders in water-intensive products have traditionally been out of the scope of those who studied or were responsible for good water governance, with Water Footprint Accounting these players enter the picture now as potential 'change agents'. They are important not only as direct but also as indirect water users.

The water footprint concept was introduced in 2002. Prior to this, there had been few thoughts in the science and practice of water management about water consumption and pollution along whole production and supply chains. As a result, there was limited awareness that the organization and characteristics of a production and supply chain strongly

influence the volumes (and temporal and spatial distribution) of water consumption and pollution that can be associated with a final consumer product. Visualizing the hidden water use behind products can assist in understanding the global character of freshwater and in quantifying the effects of consumption and trade on water resources use (Hoekstra and Hung 2005; Hoekstra and Chapagain 2008). The improved understanding can form a basis for a better management of the globe's freshwater resources.

The idea of considering water use along supply chains gained interest after the introduction of the 'water footprint' concept (Hoekstra 2003). The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer. It can be regarded as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution. The various components of a total water footprint are specified geographically and temporally. As an indicator of 'water use', the water footprint differs from the classical measure of 'water withdrawal' in three respects. First, it is not restricted to blue water use, but also includes green and grey water. Second, it is not restricted to direct water use, but also includes indirect water use. Third, it does not include blue water use insofar as this water is returned to where it came from. The water footprint thus offers an alternative perspective on how a consumer or producer relates to the use of freshwater systems. It is a volumetric measure of water consumption and pollution. Water Footprint Accounts give spatiotemporally explicit information on how water is appropriated for various human purposes. They can feed the discussion about sustainable and equitable water use and allocation and also form a good basis for a local assessment of environmental, social and economic impacts.

This chapter provides an overview of the new field of Water Footprint Accounting, mostly drawing from the *Water Footprint Assessment Manual* as published by the Water Footprint Network (Hoekstra et al. 2011). The interest in Water Footprint Accounting is highly diverse. Some companies use the water footprint to map their operational and supply-chain water use. Some of the frontrunners in this field are the Coca-Cola Company, SABMiller and Unilever. Investors like the International Finance Corporation consider the concept as a relevant tool to explore the risks of companies associated with water use in their supply chain. A government that has made first steps to incorporate the water footprint into national legislation is Spain, which requires Water Footprint Accounting to be part of drafting river basin plans. Finally, environmental organizations such as WWF and The Nature Conservancy use the concept for awareness raising and pushing governments and businesses towards good water stewardship.

GOALS AND SCOPE OF WATER FOOTPRINT ACCOUNTING

Water footprint studies may have various purposes and be applied in different contexts. Each purpose requires its own scope of analysis and will allow for different choices when making assumptions. When companies apply the water footprint as a metric to quantify their operational and supply-chain water footprint, the target can be, for example, identifying where they contribute to regional hotspots of water overexploitation or pollution, formulating a corporate water strategy, or setting specific quantitative water footprint reduction targets. In the cases where environmental organizations apply the water footprint, they aim at raising awareness in some instances, but other times they go beyond that by aiming at the identification of regional hotspots that need attention or at feeding the debate about the need for water footprint reduction. The purpose for which it is intended determines the water footprint detail required. If the purpose is raising awareness, national or global average estimates for the water footprints of products are probably sufficient. When the goal is hotspot identification, it is necessary to include more detail so that it is possible to exactly pinpoint where and when the water footprint has most environmental, social or economic impacts. If the aim is to have a database for the formulation of policy and establishment of targets on quantitative water footprint reduction, an even higher degree of spatial and temporal detail is required. Further, the water footprint assessment should be embedded in a broader deliberation incorporating factors other than water alone.

Water footprints can be assessed at different levels of spatiotemporal detail as depicted in Table 3.1. At the lowest level of detail, the water footprint is assessed based on global average water footprint data from an available database. At the highest level of detail, water footprint accounts are geographically and temporally explicit, based on precise data on inputs used, and precise sources of those inputs.

The water footprint of one single 'process step' is the basic building block of all Water Footprint Accounts (refer to Figure 3.1). The water footprint of an intermediate product such as cotton lint or a final product

Table 3.1 Spatiotemporal explication in Water Footprint Accounting

	Spatial Explication	Temporal Explication	Source of Required Data on Water Use	Typical Use of the Accounts
Level A	Global average	Annual	Available literature and databases on typical water consumption and pollution by product or process	Awareness raising, rough identification of components contributing most to the overall water footprint, development of global projections of water consumption
Level B	National, regional or catchment specific	Annual or monthly	As above, but use of nationally, regionally or catchment-specific data	Rough identification of spatial spreading and variability, knowledge base for hotspot identification and water allocation decisions
Level C	Locally, site and field specific	Monthly or daily	Empirical data or (if not directly measurable) best estimates on water consumption and pollution, specified by location and over the year	Knowledge base for carrying out a water footprint sustainability assessment, formulation of a strategy to reduce water footprints and associated local impacts

such as a cotton shirt is the aggregate of the water footprints of the various process steps relevant in the production of the product. The water footprint of an individual consumer is a function of the water footprints of the various products consumed by the consumer. The water footprint of a community of consumers is equal to the sum of the individual water footprints of the members of the community. The water footprint of a producer is equal to the sum of the water footprints of the products that the producer delivers. The water footprint within a geographically delineated area is equal to the sum of the water footprints of all processes taking place in that area.

A water footprint is expressed in terms of a water volume per unit of

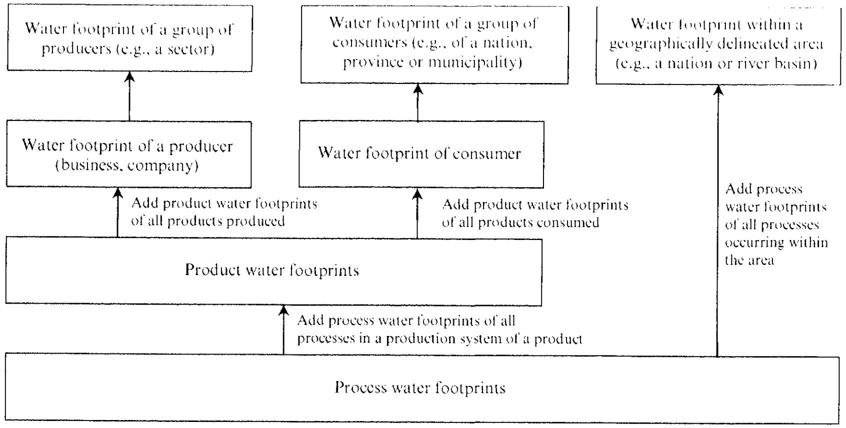

Figure 3.1 *Coherence between the different sorts of Water Footprint Accounts*

product or as a water volume per unit of time. The water footprint of a process is expressed as water volume per unit of time. When divided over the quantity of product that results from the process, it can also be expressed as water volume per product unit. A product water footprint is expressed in terms of water volume per unit of product (usually m^3/ton or litre/kg). The water footprint of a consumer or producer or the water footprint within an area is expressed as water volume per unit of time, which may be daily, monthly or yearly.

THE WATER FOOTPRINT OF A PROCESS STEP

The blue water footprint refers to consumption of blue water resources (surface- and groundwater) along the supply chain of a product. The term 'consumptive water use' refers to one of the following four cases: (1) water evaporation, (2) water incorporation into a product, (3) water not returning to the same catchment area (for example, it is returned to another catchment area or the sea) or (4) water not returning in the same period (for example, it is withdrawn in a scarce period and returned in a wet period). The first component, evaporation, is generally the most significant one. 'Consumptive water use' does not mean that the water disappears, because most water on earth remains within the cycle and always returns somewhere. Water is a renewable resource, but that does not mean that its availability is unlimited. The blue water footprint measures the amount of water available in a certain period that is consumed. The

remainder is left to sustain the ecosystems that depend on the ground- and surfacewater flows.

The green water footprint is the volume of green water (that is, rainwater) consumed during the production process. This is particularly relevant for agricultural and forestry products (such as products based on crops or wood), where it refers to the total rainwater evapotranspiration from fields and plantations plus the water incorporated into the harvested crop or wood.

The grey water footprint of a process step is an indicator of the degree of freshwater pollution that can be associated with the process step. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. In other words, it refers to the volume of water that is required to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards. The grey component of water use, expressed as a dilution water requirement, has been recognized by Postel et al. (1996) and Chapagain et al. (2006). The grey water footprint is calculated by dividing the pollutant load (mass/time) by the difference between the maximum acceptable concentration for that pollutant and its natural concentration in the receiving water body (mass/volume). When chemicals are directly released into a surfacewater body, the load can directly be measured. When a chemical is applied on or put into the soil, like in the case of solid waste or use of fertilizers or pesticides, it may happen that only a fraction seeps into the groundwater or runs off over the surface to a surfacewater stream. In this case, the pollutant load is the fraction of the total amount of chemicals applied that reaches the ground- or surfacewater.

When a waste flow concerns more than one form of pollution, as is generally the case, the grey water footprint is determined by the pollutant that is associated with the largest pollutant-specific grey water footprint.

THE WATER FOOTPRINT OF A PRODUCT

The water footprint of a product is estimated by considering water consumption and pollution in all steps of the production chain. Although the water footprint is an indicator,that is explicit in time and space, for the purpose of awareness raising and rough comparison of products, total, global average water footprints calculated over a number of years can be presented. Table 3.2 presents global average water footprints of selected commodities.

Table 3.2 The global average water footprint of some selected commodities

Commodity	Unit	Water Footprint (litres)
Apple or pear	1 kg	700
Banana	1 kg	860
Beef	1 kg	15 500
Beer (from barley)	1 glass of 250 ml	75
Bio-diesel from soybean	1 litre	14 000
Bio-ethanol from maize	1 litre	2 600
Bio-ethanol from sugar beet	1 litre	1 400
Bio-ethanol from sugar cane	1 litre	2 500
Bread (from wheat)	1 kg	1 300
Cabbage	1 kg	200
Cheese	1 kg	5 000
Chicken	1 kg	3 900
Chocolate	1 kg	24 000
Coffee	1 cup of 125 ml	140
Cotton	1 shirt of 250 gram	2 700
Cucumber or pumpkin	1 kg	240
Dates	1 kg	3 000
Eggs	1 60-gram egg	200
Goat meat	1 kg	4 000
Groundnuts (in shell)	1 kg	3 100
Leather (bovine)	1 kg	17 000
Lettuce	1 kg	130
Maize	1 kg	900
Mango	1 kg	1 600
Milk	1 glass of 250 ml	250
Milk powder	1 kg	4 600
Olives	1 kg	4 400
Orange	1 kg	460
Paper	1 A4 (80 gram/m^2)	10
Pasta (dry)	1 kg	1 900
Peach or nectarine	1 kg	1 200
Pizza margherita	0.725 kg	1 200
Pork	1 kg	4 800
Potato	1 kg	250
Rice	1 kg	3 400
Sheep meat	1 kg	6 000
Sugar (from sugar cane)	1 kg	1 500
Sugar (from sugar beet)	1 kg	935
Tea	1 cup of 250 ml	30
Tomato	1 kg	180
Wine	1 glass of 125 ml	120

Sources: Hoekstra and Chapagain (2008); Water Footprint Network (2010).

In order to estimate the water footprint of a product it is necessary to specify the production system, which generally consists of some sequential process steps. A (simplified) example of the production system of a cotton shirt is: cotton growth, harvesting, ginning, carding, knitting, bleaching, dying, printing and finishing. In reality, production systems are often complex networks of linked processes, in many cases even circular. If the intention is to go beyond a very superficial analysis based on global averages, the process steps in time and space need to be specified, requiring the origin of the (inputs of the) product to be traced. Production circumstances and process characteristics will differ from place to place, so that place of production will influence the size and colour of the water footprint. Keeping track of where all processes take place is necessary to be able to geographically map the water footprint of a final product.

The water footprint of a product can be calculated in two ways. The simple chain-summation approach can be applied when a production system produces only one output product. In this case, the water footprints that can be associated with the various process steps in the production system can all be fully attributed to the product that results from the system. The water footprint of a product (volume per product unit or mass) is equal to the sum of the relevant process water footprints (volume/time) divided by the production quantity of the product (product units or mass/time). The step-wise accumulative approach is more generic. Suppose we have a number of input products when making another number of output products. The sum of the water footprints of the input products needs to be distributed over the various output products, which can be done proportionally to the value of the output products. Suppose that processing of y input products ($i = 1$ to y) results in z output products ($p = 1$ to z). If during processing there is some water use involved, the process water footprint is added to the water footprints of the input products before the total is distributed over the various output products. The water footprint of output product p is calculated as per Equation (3.1):

$$WF_{prod}[p] = \left(WF_{proc}[p] + \sum_{i=1}^{y} \frac{WF_{prod}[i]}{f_p[p, i]} \right) \times f_v[p] \qquad (3.1)$$

where $WF_{prod}[p]$ is the water footprint (volume/mass) of output product p, $WF_{prod}[i]$ the water footprint of input product i and $WF_{proc}[p]$ the process water footprint of the processing step that transforms the y input products into the z output products, expressed in water use per unit of processed product p (volume/mass). Parameter $f_p[p,i]$ is a so-called 'product fraction' and parameter $f_v[p]$ is a 'value fraction'. The product fraction of an output product p that is processed from an input product i is defined as the mass of the output product obtained per mass of input product. The value fraction of an output product p is defined as the ratio of the market value of this product to the aggregated market value of all the output products (p = 1 to z) obtained from the input products as depicted in Equation (3.2):

$$f_v[p] = \frac{price[p] \times w[p]}{\sum_{p=1}^{z} (price[p] \times w[p])} \tag{3.2}$$

where $price[p]$ refers to the price of product p (monetary unit/mass). The denominator is summed over the z output products (p=1 to z) that originate from the input products.

THE WATER FOOTPRINT OF CONSUMERS

The water footprint of a consumer is defined as the total volume of freshwater consumed and polluted for the production of the goods and services consumed by the consumer. It is calculated by adding the direct water footprint of the individual and his/her indirect water footprint. The direct water footprint refers to the water consumption and pollution that is related to water use at home or in the garden. The indirect water footprint refers to the water consumption and pollution of water that can be associated with the production of the goods and services consumed by the consumer. It refers to the water that was used to produce, for example, the food, clothes, paper, energy and industrial goods consumed. The indirect water use is calculated by multiplying all products consumed by their respective product water footprint (which, for each product, will depend on the origin of the product). The set of products to be considered refers to the full range of final consumer goods and services. The water footprints of final private goods and services are exclusively allocated to the consumer of the private good. The water footprints of public or shared goods and services are allocated to consumers based on the share that each individual consumer takes.

NATIONAL WATER FOOTPRINT ACCOUNTING

Traditional national water use accounts only refer to the water withdrawal within a country (Gleick 1993). They do not distinguish between water use

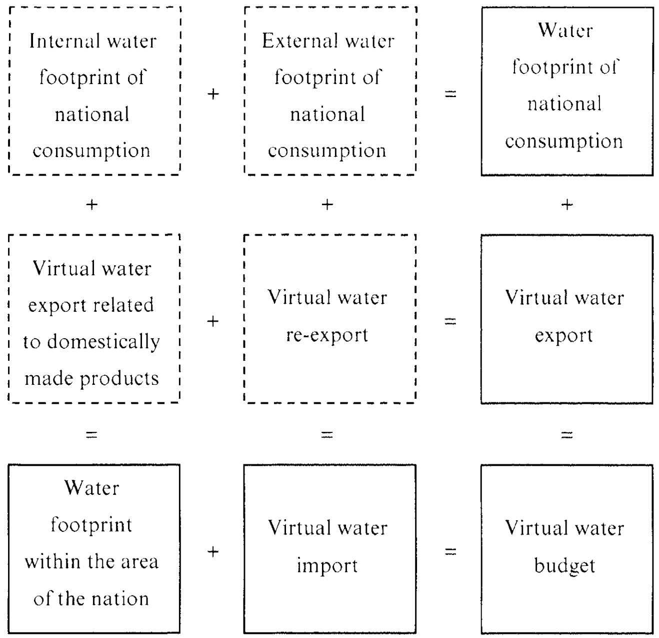

Figure 3.2 The national Water Footprint Accounting scheme

for making products for domestic consumption and water use for producing export products. They also exclude data on water use outside the country to support national consumption. In order to support a broader sort of analysis and better inform, the national water use accounts can be extended. Figure 3.2 is a visual representation of the national Water Footprint Accounting scheme introduced by Hoekstra and Chapagain (2008).

The water footprint of the consumers in a nation has two components. The internal water footprint of national consumption is defined as the use of domestic water resources to produce goods and services consumed by the national population. It is the sum of the water footprint within the nation minus the volume of virtual water export to other nations insofar as related to the export of products produced with domestic water resources. The external water footprint is defined as the volume of water resources used in other nations to produce goods and services consumed by the population in the nation considered. It is equal to the virtual water import into the nation minus the volume of virtual water export to other nations as a result of re-export of imported products.

The virtual water export from a nation consists of exported water of domestic origin and re-exported water of foreign origin. The virtual water import into a nation will partly be consumed, thus constituting the external water footprint of national consumption and partly be re-exported. The sum of the virtual water import into a country and the water footprint within the area of the nation is equal to the sum of the virtual water export from the nation and the water footprint of national consumption. This sum is called the virtual water budget of a nation. Table 3.3 shows the main components of the national Water Footprint Accounts for a number of selected countries compiled by Hoekstra and Chapagain (2007, 2008).

The water footprint within a nation (volume/time) is defined as the total freshwater volume consumed or polluted within the territory of the nation. It can be calculated by summing the water footprints of all water-consuming or polluting processes taking place in the nation. The water footprint of national consumption can be calculated through two alternative approaches. In the top-down approach, the water footprint of national consumption is calculated as the water footprint within the nation plus the virtual water import minus the virtual water export. The gross virtual water import is calculated by multiplying import volumes of various products by their respective product water footprint in the nation of origin. The gross virtual water export is found by multiplying the export volumes of the various export products by their respective product water footprint. The bottom-up approach is based on the method of calculating the water footprint of a group of consumers. The group of consumers consists of the inhabitants of a nation. The water footprint of national consumption is calculated by adding the direct and indirect water footprints of consumers within the nation.

The top-down calculation can theoretically give a slightly higher (lower) figure if the stocks of water-intensive products increase (decrease) over the year. Another drawback of the top-down approach is that there can be delays between the moment of water use for production and the moment of trade. For instance, in the case of trade in livestock products this may happen: beef or leather products traded in one year originate from livestock raised and fed in previous years. Part of the water virtually embedded in beef or leather refers to water that was used to grow feed crops in previous years. As a result of this, the balance presumed in the top-down approach will hold over a period of a few years, but not necessarily over a single year.

The bottom-up approach depends on the quality of consumption data, while the top-down approach relies on the quality of trade data. The outcome of the top-down approach can be very vulnerable to relatively small errors in the input data when the import and export of a country are large relative to its domestic production, which is typical for relatively

Table 3.3 The main components of the national Water Footprint Accounts for some countries for the period 1997–2001 (in Gm³/yr)

Country	Internal WF of National Consumption	External WF of National Consumption	WF of National Consumption	Virtual Water Export Related to Domestically Made Products	Virtual Water Re-export	Virtual Water Export	Water Footprint Within the Area of the Nation	Virtual Water Import	Virtual Water Budget
Argentina	48	3	52	48	2	51	97	6	102
Brazil	216	18	234	63	5	68	278	23	301
China	826	57	883	67	6	73	893	63	956
Egypt	56	13	70	2	0	3	59	14	72
France	69	41	110	47	31	79	117	72	189
Germany	60	67	127	32	38	70	92	106	197
India	971	16	987	41	1	43	1013	17	1030
Indonesia	242	28	270	23	3	25	265	30	295
Japan	52	94	146	3	4	7	54	98	153
South Africa	31	9	39	6	2	9	37	11	48
UK	22	51	73	5	13	18	27	64	91
USA	566	130	696	184	46	229	750	176	925

Note: Gm^3 = billion cubic metres.

Source: Hoekstra and Chapagain (2007, 2008).

small nations specializing in trade. Van Oel et al. (2009) report the water footprint for the Netherlands using the top-down approach and demonstrate its sensitivity to the import and export data used. Relative small errors in the estimates of virtual water import and export translate into a relatively large error in the water footprint estimate. In such a case, the bottom-up approach will yield a more reliable estimate than the top-down approach. In nations where trade is relatively small compared to domestic production, the reliability of the outcomes of both approaches will depend on the relative quality of the databases used for each approach.

The accounting scheme as described for a nation can also be applied for other geographical units. In general terms, the water footprint within an area is defined as the total freshwater consumption and pollution within the boundaries of the area. The area can be a catchment area, a river basin, a province, state or nation or any other hydrological or administrative spatial unit. The water footprint within a geographically delineated area is calculated as the sum of the process water footprints of all water using processes in the area.

WATER FOOTPRINT OF A BUSINESS

The water footprint of a business is defined as the total volume of freshwater that is used directly or indirectly to run and support the business. The operational (or direct) water footprint of a business is the volume of freshwater consumed or polluted due to its own operations. The supply-chain (or indirect) water footprint of a business is the volume of freshwater consumed or polluted to produce all the goods and services that form the inputs of production of the business. A further differentiation is possible between the water footprint that can be immediately associated with the product(s) produced by the businesses and the 'overhead water footprint'. The latter is defined as the water footprint pertaining to the general activities for running a business and to the general goods and services consumed by the business. The term 'overhead water footprint' is used to identify water consumption that is necessary for the continued functioning of the business but that does not directly relate to the production of one particular product. In every case, the green, blue and grey water footprint component can be distinguished. Examples of the various components in a business water footprint are given in Table 3.4.

In addition to the operational and supply-chain water footprint, a business may distinguish an 'end-use water footprint' of its product. This is the water consumption and pollution by consumers when using the product. Strictly speaking, the end-use water footprint of a product is not part of

Table 3.4 Examples of the components of a business water footprint

Operational Water Footprint		Supply-chain Water Footprint	
Water footprint directly associated with the production of the business's product(s)	Overhead water footprint	Water footprint directly associated with the production of the business product(s)	Overhead water footprint
Water incorporated into the product Water consumed or polluted through a washing process Water thermally polluted through use for cooling	Water consumption or pollution related to water use in kitchens, toilets, cleaning, gardening, or washing working clothes	Water footprint of product ingredients bought by the company Water footprint of other items bought by the company for processing their product	Water footprint of infrastructure (construction materials etc.) Water footprint of materials and energy for general use (office materials, cars and trucks, fuels, electricity, etc.)

the business water footprint or the product water footprint, but part of the consumer's water footprint. Water consumption or pollution by a consumer when using a product depends on the habits of the consumer, but sometimes it also depends on the characteristics of the product. For example, the water pollution that results from the use of soaps in the household depends on the ingredients of the soap and the harm they can do when discharged into ambient water. Companies can influence this through the design of their products.

Business Water Footprint Accounting can inform the development of a well-informed corporate water strategy because the water footprint as an indicator of water use differs from the indicator 'water withdrawal in the own operations' currently used by many companies. Companies have traditionally focused on water use in their operations, not in their supply chain. Most companies will discover that their supply-chain water footprint is much larger than their operational footprint. It may be more cost effective to shift investments from efforts to reduce operational water use to efforts to reduce the supply-chain water footprint and associated risks.

For business Water Footprint Accounting, it is necessary to define the business units that will be considered and specify the annual inputs and outputs per business unit (in physical units). The operational water footprint of a business unit is equal to the consumptive water use and the water pollution that can be associated with the operations of the business. A simple approach is to include the evaporative flow from the operations, the volume of water incorporated into products and the return flows of water to catchments other than from where water was withdrawn. In addition, the effluent volumes and concentrations of chemicals therein should be considered. The operational overhead water footprint (water consumption and pollution related to general water-using activities in the business unit) can be identified and quantified just like the operational water footprint directly associated with the production process. The overhead water footprint, however, will often serve more than the business unit considered. For example, the overhead of a factory with two production lines will have to be distributed over the two production lines. If a business unit refers to one of the production lines, the share of the overhead water footprint that is to be apportioned to that production line can be estimated based on the production value of that production line relative to the value of the other production line.

The supply-chain water footprint per business unit (volume/time) can be calculated by multiplying the various input product volumes (that is, data available from the business itself) by their respective product water footprints (that is, data obtained from suppliers). The product water footprint depends on the source of the product. When the product comes from another business unit within the same business, the value of the product water footprint is known from the business's accounting system. When the product originates from a supplier outside the own business, the value of the product water footprint has to be obtained from the supplier or estimated based on indirect data known about the production characteristics of the supplier. The various product water footprints are the aggregation of the green, blue and grey footprints. Accordingly, the supply-chain water footprint for a business unit can be disaggregated into its blue, green and grey components.

The water footprint of each specific output product of a business unit (volume/product unit) is estimated by dividing the business unit water footprint (volume/time) by the output volume (product units/time). Allocation of the water footprint over the output products can be done in several ways, for example, according to mass, energy content or economic value. Following what is common in life-cycle assessment studies, it is recommended to allocate according to economic value. The rationale behind this economic allocation is that the final economic value obtained is the reason for the use of resources and thus the water footprint. Therefore, it is reasonable to allocate the total water footprint to a greater extent to the primary products of a process and to a lesser extent to the (lower value) secondary or by-products.

CONCLUSION

Traditional statistics on water use, whether national or corporate accounts, are mostly restricted to water withdrawals, thereby ignoring green and grey water use and disregarding indirect use as well. In the case of business accounts, the traditional approach pays no attention to water consumption and pollution in the supply chain. In the case of national accounts, the conventional approach overlooks virtual water imports and exports and the fact that part of the water footprint of national consumption lies outside the country. It is desirable to gradually start incorporating water footprint statistics in governmental statistics and featuring them in international statistics. In the case of companies, it is desirable to incorporate Water Footprint Accounts in corporate environmental and sustainability reporting. In this way, governments and companies have a more comprehensive picture of their direct and indirect appropriation of freshwater resources, enabling them to develop better-informed water policies.

The water footprint, introduced in 2002 (Hoekstra 2003), is part of a family of footprint concepts. The oldest footprint concept is the ecological footprint, introduced in the 1990s by Rees (1992) and Wackernagel and Rees (1996). The ecological footprint measures the use of available bioproductive space and is measured in hectares. The carbon footprint concept originates from the ecological footprint discussion and has started to become more widely known since 2005 (Safire 2008). The carbon footprint refers to the sum of greenhouse gas emissions caused by an organization, event or product and is expressed in terms of CO_2 equivalents. Although the carbon footprint concept is relatively young, the idea of accounting greenhouse gas emissions is already much older; the first assessment of the Intergovernmental Panel on Climate Change, for example, already dates back to 1990. Older than the ecological and carbon footprint concepts are also the concepts of 'embodied energy' and 'emergy' as applied in energy studies (Odum 1996; Herendeen 2004). These concepts refer to the total energy used to produce a product and are expressed in joules.

The various 'footprint' concepts are to be regarded as complementary indicators of natural capital use in relation to human consumption (Hoekstra 2009). Looking at only area requirements or only water or energy requirements is insufficient. Available land, freshwater and energy are all critical factors in development. A challenge for future research is to bring the various footprint concepts and related methods together in one consistent conceptual and analytical framework. A further challenge is to link water footprint accounts to material flow analysis, input–output modelling (Zhao et al. 2009) and life cycle assessment (Milà i Canals et al. 2009).

The water footprint is a relatively new concept and Water Footprint Accounting is a method only recently recognized as a useful tool by both governments and companies. In practical implementation, various challenges remain, including the development of practical guidelines per product category and business sector on how to truncate the analysis (where to stop going back along supply chains) and rules on how to account for uncertainties and how to deal with time variability when doing trend analysis. The challenge is to develop databases on typical process water footprints (the basic ingredient for each analysis) and tools to make it easier for practitioners to set up a water footprint account.

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