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Fresh Water Resources in the Changing Wealth of Nations

Scoping chapter

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Fresh Water Resources in the Changing Wealth of Nations
Scoping chapter

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1 Introduction

Freshwater is vital for life. It is crucial for human sustenance, nature, agriculture, and nearly all economic processes. In the past, many human settlements have been founded in the vicinity of a freshwater resource (e.g., Fang & Jawitz, 2019). Although water has proven to be a source of collaboration, water shortages and disputes have also led to conflict, and still do.[1] Yet, water as a natural asset and source of wealth has so far not been included separately in the Changing Wealth of Nations (CWON; World Bank 2018).[2]

As is the case with other (natural) assets, valuing freshwater resources in monetary terms on a global and national scale is challenging. Complexities arise due to several reasons. To mention a few:

- Out of the total freshwater resources on earth (only 2.5% of total global water reserves), 70% is stored in ice and glaciers, 30% in groundwater systems and only 0.3% in lakes and rivers.
- Water is mobile: it evaporates, precipitates, infiltrates, drains and runs-off into the sea.
- The temporal variability of available water resources is high, showing seasonal and annual fluctuations; furthermore, extremes can cause floods and droughts;[3]
- Demographic growth, economic development and climate change increase the pressure on freshwater resources, leading to a degradation of the resource (e.g. overexploitation, pollution and salinization) and its catchment area (e.g., deforestation), and to several water related problems (e.g., subsidence).
- There are many different water users, including humans, nature and economic sectors. Water provides many different benefits to these users: the provision of drinking water, the supply of water for agriculture and industries, but also several regulating and cultural ecosystem services. These benefits represent different values, which require separate valuation approaches.
- Water resources are often transboundary with different uses and economic value across countries, which makes it difficult to allocate water resources and their values to particular countries.

Despite these complexities, it is important that freshwater resources are valued and managed in a sustainable way. In this chapter, we present a roadmap to value fresh water resources on a global scale in a manner that is broadly consistent with the SNA and SEEA principles used for the valuation of other assets in CWON. The approach to asset valuation is based on the concept that the value of an asset should equal the discounted stream of expected net earnings (resource rents) generated over its lifetime. Much of produced capital is widely marketed and the market price is a reasonable reflection of its value. Other assets - like fossil fuel reserves - may not be traded in markets, but the products of these assets - the extracted fossil fuels - do have a market price and the implicit rent attributable to the asset can be reasonably derived from this price and the costs to extract these fuels.

[1] See for example http://www.worldwater.org/conflict/map/.
[2] The text in this report is written as a chapter for the upcoming 2020/2021 World Bank publication Changing Wealth of the Nation.
[3] Over the last 30 years, economic losses in EM-DAT (CRED, 2018) amount to an average of US$ 31.4 billion for floods and US$ 5.4 billion USD for droughts, while the number of people affected averages 106 million for floods and 55 million for droughts (PBL et al., 2018, The Geography of Future Water Challenges)

This approach has also been applied to other assets in the CWON, like agricultural land and timber forests. In the CWON, for these assets, for each country, an asset value V is calculated as the discounted sum of annual rents, R_t, over the lifetime, T, with a real discount rate, r, of 4% per year. For resources that are managed sustainably, the CWON core accounts assume a time horizon T of 100 years. In the case of renewable resources, the time horizon can be less when extraction exceeds natural regeneration and hence sustainability is at stake. For simplicity of exposition here, we do not assume any growth in rents and have omitted the subscripts for country:

$$V = \sum_{t=\tau}^{T} \frac{R_t}{(1+r)^t} \quad \text{[Eq. 1]}$$

R_t is calculated simply as the price, p, times quantity, q, minus the related costs for extraction, purification, distribution, etc., c:

$$R_t = (p \times q) - c \quad \text{[Eq. 2]}$$

In the case of a water resource, the time horizon, T, is calculated as either

$T = 100\ if\ q < z$, where z is the average annual replenishment,

or the volume of the water resource Q divided by the difference between average annual extraction q and average annual replenishment z:

$$T = \frac{Q}{q-z};\ T \leq 100 \quad \text{[Eq. 3]}$$

When rents, R_t, are negative, the value of the asset is assumed to be zero. This situation can occur for some resources like fossil fuels and minerals in years when the market price is lower than the per unit cost. It can also occur when the extraction of a resource is heavily subsidized, such as the production of renewable energy in early years, or the capture of marine fisheries. Water poses similar challenges as well, because the tariff charged, if any, often does not even cover the full costs of supply, let alone any scarcity charge.

The value of a freshwater resource is not only determined by its quantity q, but also by its quality. Water quality has an impact on the costs to purify and re-use water (variable c in Eq. 2). Hence, (future) efforts to reduce water pollution will increase the (future) value of freshwater resources. The present roadmap, however, has a focus on water quantities and assumes existing qualities (and hence costs c). Integrating water quality in the roadmap should be considered as a future addition.

In this chapter, the roadmap for fresh water asset valuation is developed through the following sections:

- section 2 provides an overview of available data and models to determine the physical water flows (q, z) and stocks (Q), and provides a global and national picture of water use and availability;
- section 3 discusses different approaches to value water for different water uses, and the data to estimate values (p) and costs (c), or approximations of these. It also presents a first estimate of the total global asset value of water, V; and
- section 4 presents the roadmap.

The chapter is accompanied by a separate (online) background paper.[4]

[4] Here presented as Appendixes A, B and C.

2 Global freshwater resources: data, models and overview

Physical data on freshwater resources for the valuation of water includes data on different water uses (q), water stocks (Q), and replenishment (z). To be included in the CWON, the water data should:

- allow for trend analysis, hereto data should cover multiple decades (1990 - 2019), or should provide sufficient input to interpolate missing years;
- be available for at least 100 countries; and
- provide a consistent and heterogeneous assessment ensuring inter- comparability between the countries.

In this section, we review databases and hydrological models which can be used for this purpose.

2.1 Global water databases

The collection of data on various water uses has improved significantly over the last decades. It is collated in databases from different international organizations. In addition, national statistical offices have intensified their data collection on physical freshwater quantities as part of the programs for the System of Environmental-Economic Accounts (SEEA). Table 1 provides an overview of water databases with annual data and global or continental coverage.

Table 1: Overview of the identified databases

	AQUASTAT	EUROSTAT	OECD. Stat	WISE	WRR	UNSD	Water Risk Filter	WASH
Publisher	FAO	European Commission	OECD	EEA	WRI	UN	WWF	UNICEF/WHO
Geographic coverage	Global	Europe	Global	Europe	Global	Global	Global	Global
Spatial resolution	National/ Regional	National/State/ RBD	National	National, RBD, Sub-unit	Regional, National	National	Sub-basins	National
Time coverage	1958-2017	1970-2016	1970-2016	2002-2012	1959-2011 + future projections	1990-2016	2000 – present + future projections	1950-2019
Relevant variables	• Sectoral surface water abstracted • Ground-water abstracted • Fresh water abstracted as the proportion of renewable water • Renewable freshwater water resources	• Sectoral surface water abstractions • Fresh groundwater abstracted • Renewable freshwater resources	• Renewable freshwater resources • Total water abstractions • Return flow • Water use	• Sectoral water abstractions • Water use per supply category and economic sector	• Renewable fresh-water resources • Annual water withdrawals • Water stress Index • Modelled water availability and use for current and future climate conditions	• Sectoral water abstracted • Net freshwater supplied • Renewable fresh water resources	• Renewable fresh water resources • Water scarcity • Aridity • Water depletion • Baseline water stress • Access to safe drinking water • Future water discharge and water stress	• Proportion of population using: • drinking water services • sanitation services • piped drinking water sources • sanitation facilities connected to sewer networks
Main data sources	• National Statistical Institutes • Modelled values • Eurostat/ UNSD/OECD	• OECD/Eurostat Joint Question-naire • National Statistical Institutes • Agricultural institutes • Universities	• OECD / Eurostat Joint Question-naire • National Statistical Institutes • AQUASTAT	• Obligated National WFD reports of EEA member countries and cooperating countries	• AQUASTAT / PCR-GLOBWB and other sources	• National Statistical Institutes • UNSD/UNEP Question-naire • AQUASTAT	• OECD • CGIAR • WRI • WaterGAP • UN IGRAC • UNICEF / WHO • Various scientific publications	• National Statistical Institutes

Overall, AQUASTAT is the most extensive global database in which data from various sources are gathered. AQUASTAT also delivers data to other databases. The dataset covers the past 50 years at country level and includes sectoral demands (q in Eq. 2): domestic, industry and agriculture, groundwater and surface water withdrawal, and is completed with some water availability indicators on renewable water resources. Especially in developing countries, there are gaps in the data, and in some countries data collection started later.

The above databases do not contain information on (non-renewable) water stocks (Q) or on replenishment (z). WASH global data on drinking water and sanitation is supplementary to the data from AQUASTAT. This data is especially relevant when water quality issues are further integrated in the roadmap.

2.2 Global hydrological models

Global water valuation cannot rely on the data from the databases presented in the previous section alone. Global hydrological models (GHMs) provide a means to tackle several issues in the data, including:

- supplementing the (observational datasets) for countries with limited data availability through interpolation and modelling;
- providing information on (non-renewable) water stocks (esp. groundwater stocks);
- providing information on lower spatial levels than that of countries;
- improving the understanding of - and coherence between - physical water stocks and flows; and
- exploring future climate change and socio-economic scenarios and their influence on future water demand, availability and use.

Table 2 provides an (non-exhaustive) overview of different GHMs that can be considered. Those models simulate surface water flows, estimate surface water and groundwater stocks (Q) and estimate groundwater replenishment (e.g. recharge, z).

Table 2: Overview of Global Hydrological Models

Model	Water demand / use	Water abstractions	Replenishment of groundwater	Quantification of groundwater resources	Reservoirs	Spatial resolution	Reference
WaterGAP3	Yes	Yes, distinction between ground and surface water	Yes	Approximation	Yes, with regulation routine	5 arc min / ~10 km	Flörke et al.,2013
PCR-GLOBWB	Yes	Yes, distinction between ground and surface water	Yes	Approximation	Yes, with regulation routine	5 arc min / ~10 km	Sutanudjaja et al., 2018
LISFLOOD	No	Not implemented for all demands globally	Yes	Approximation	Yes, simple weir + downstream ecological demand	0.1 degrees / ~10 km	Van Der Knijff et al., 2010
W3RA	No	Not implemented for all demands globally	Yes	Approximation	No	5 arc min / ~10 km	van Dijk et al., 2014
H08	Yes	Yes, distinction between ground and surface water	Yes	Approximation	Yes, with regulation routine	0.5 degrees	Hanasaki et al., 2018
HYPE	Yes	Yes, distinction between ground and surface water	Yes	Approximation	Yes, regulated	catchments	Lindström et al., 2010
VIC	No	Not implemented for all demands globally	Yes	Approximation	Yes, simple weir	1 km	Liang et al., 1994
MODFLOW[1]	No	Not implemented for all demands Globally	Yes	Absolute Volumes	Natural lakes	10 km	De Graaf et al., 2015

[1] Requires connection to surface water model to quantify replenishment and abstractions.

Not all of these models contain a water demand routine to estimate annual average surface and groundwater abstractions. WaterGAP3, HYPE, H08 and PCR-GLOBWB include a sectoral water demand routine which uses data from sources like AQUASTAT. Based on amongst other population data, country statistics these are downscaled to the resolution of model grids (10 km^2 or 1 km^2). The actual water abstraction and the division over ground and surface water is calculated within the models by evaluation against the simulated water availability.

WaterGAP, PCR-GLOBWB and H08 are the only models in which a reservoir regulation routine is always active, which leads to a more realistic simulation of the available freshwater stocks for irrigation, drinking water, electricity production in reservoirs.

For groundwater stocks, the GHMs give only a rough approximation of the volume and a quantification of the variation therein. A (global) groundwater model like MODFLOW is needed to provide better estimates.

2.3 Global water availability and use

For an impression of the global water demand and use data, we use data generated by PCR-GLOBWB (Sutanudjaja *et al.*, 2018). The advantage of this model is that it can be coupled to other relevant models, including MODFLOW to simulate the groundwater system and the Integrated Model to Assess the Global Environment - IAM IMAGE 3.0 (Stehfest *et al.*, 2014) that supports the simulation of land use change and socio-economic scenarios. The water data has been derived from a model run that covers the period 2000 - 2014. Meteorological input was taken from the WFDEI dataset (Weedon *et al*., 2014), produced by the European Center for Medium-Range Weather Forecasting (ECMWF). The water data is presented on three maps (Fig. 1-3), where the data is aggregated to the level of 'Water Provinces' (combinations of hydrological boundaries of river basins and the administrative boundaries of countries and provinces (Straatsma *et al*., 2020)). In future simulations the modelled period can be extended from 1995 to present, as better climate reanalysis products are becoming available (e.g., ERA5) but meteorological data are still published with a delay of around two years.

Figure 1 shows the average annual (2000-2014) freshwater availability, while Figure 2 shows the average gross water demand (note that units in the legend of Figure 2 differ by a factor 1000 compared to Figure 1). In many locations, water availability is not sufficient to fulfil actual water demand and at those locations where the required infrastructure is in place, in many cases this has led to the unsustainable depletion of groundwater resources (Gleeson *et al.*, 2010; Thomas & Famiglietti, 2019). In Figure 3, the Water Stress Index (WSI, Falkenmark, 1986) highlights where water use and water availability are unbalanced and unsustainable practices are likely to occur. The WSI is estimated with the equation:

$$WSI = D/A \quad \text{[Eq. 4]}$$

where D is the average annual demand and A is the average annual water availability. Values below 0.1 indicate low water stress, values between 0.1 and 0.2 moderate, values between 0.2 and 0.4 medium and values above 0.4 indicate high water stress.

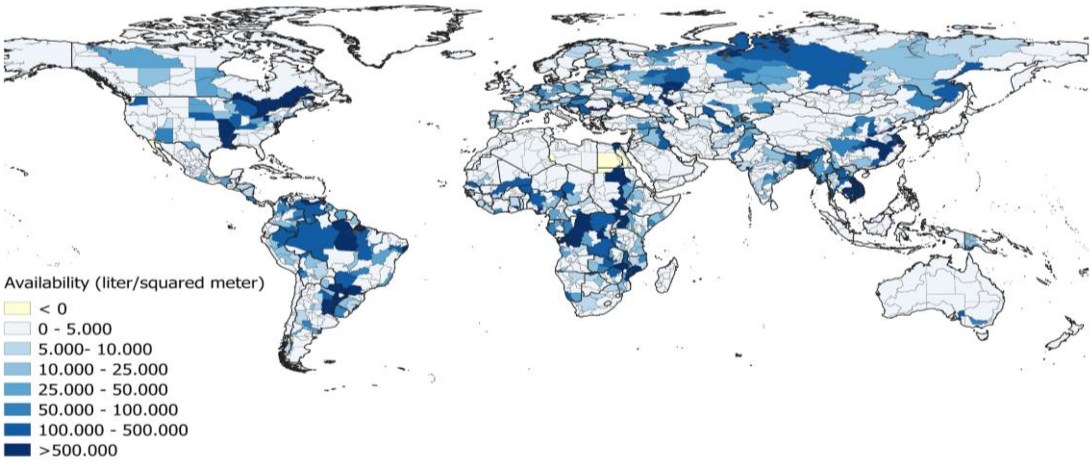

Figure 1: Average annual freshwater availability (2000-2014)

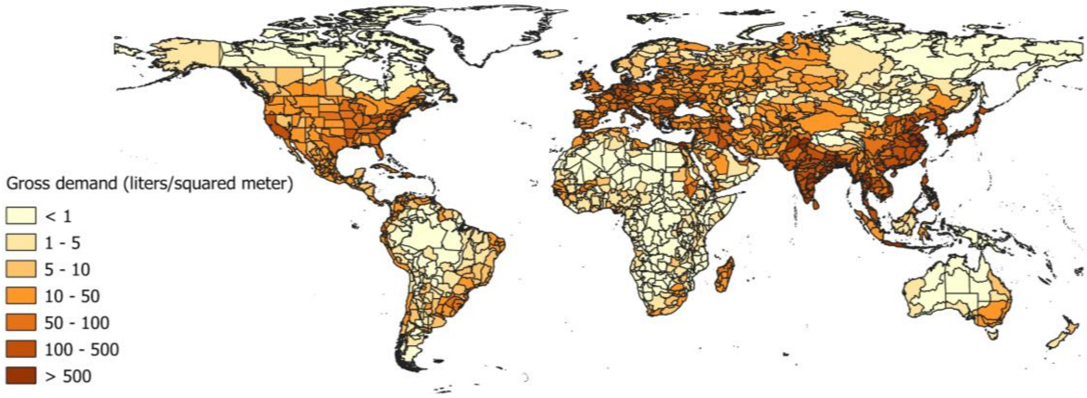

Figure 2: Average annual gross water demand (2000-2014)

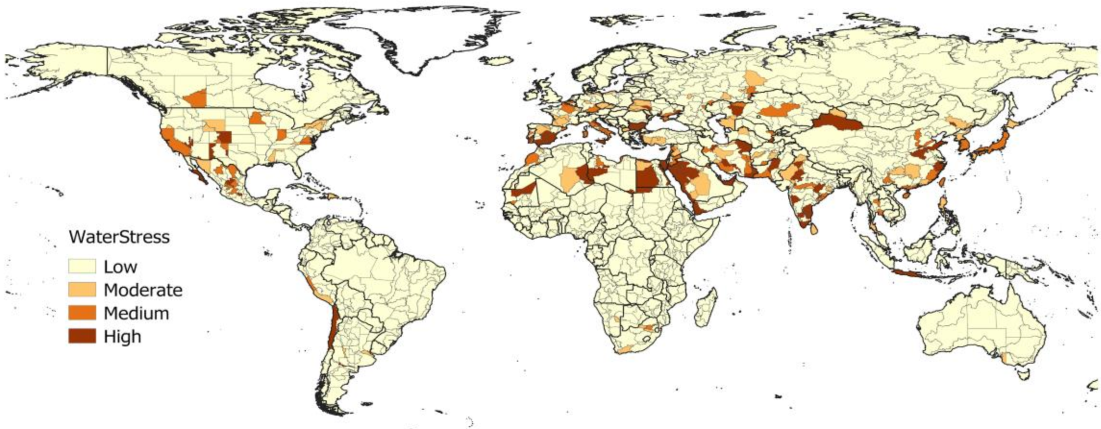

Figure 3: Water Stress Index

The Water Stress Index is the ratio between water demand and water availability. It is influenced by several factors, such as GDP per capita, land use, production activities and technologies, and climate conditions. It can give similar values for very different countries, for example developed countries in Europe and developing countries in the Sahel, whereas the underlying causes may be very different.

The map also shows that especially within larger countries, the WSI can differ significantly - see for example the values for the US, China and India. This suggests that water demand, availability and extraction are best analysed at lower spatial levels than that of countries.

Table 3 summarizes at the global level the annual average 2000-2014 gross and net water demand, actual abstractions and water use. Domestic water demand covers all domestic water uses. Irrigation water demand only covers the water that is supplied to alleviate deficits in soil moisture availability for non-paddy crops or to maintain ponded conditions for wet rice; the supplied irrigation water thus supplements the crop water requirement that cannot be replenished by rain and is increased to cover transport losses and to achieve a small but positive downward flux. Livestock demand is the amount of water required for consumption by animals. Gross demand is the demand for water withdrawn from the water system, of which part is returned as return flow. The net demand is the difference between these two. For domestic water demand, the return flow consists of waste water. For industrial water demand, a considerable part of the return flow is cooling water. The distinction between gross and net demand is not made for livestock and irrigation.[5]

Table 3: Global gross and net water demand for different water users (average over the period 2000-2014)

Use	Gross demand		Net demand		Total abstracted	Net demand satisfied (water use)
	km^3/year	%	km^3/year	%		
Domestic	368	8	221	6		
Industrial	816*	17	258	6		
Irrigation	3476	74	3476	88		
Livestock	16	0.3	16	0.4		
Total	4676	100	3971	100	3385	85%

**) This does not include hydropower*

The actual water availability, from surface water groundwater and desalinated water, can be less than the water demand, in which case the abstractions cannot satisfy the demand. Lower abstractions affect the gross demand and ultimately the net demand. The last column of Table 3 indicates that 85% of the net water demand is satisfied on an annual basis. As global information on the priority of water allocation per sector is scarce, PCR-GLOBWB distributes the abstracted water equally among all sectors and a specific percentage per sector cannot be retrieved from PCR-GLOBWB.[6]

[5] For livestock, the water demand is for drinking (no return flow). Surplus irrigation water infiltrates into the ground and contributes to the local water system. Within PCR-GLOBWB this is not quantified as a separate flux and hence gross and net demand are equal.
[6] In the remainder of this section, we assume that the 85% of the net demand is satisfied for all sectors. Country specific water use data from PCR-GLOBWB, which are the basis of Table 3, are available in a separate database.

To get insights in the validity of the model results, for three countries, the model data were compared with data compiled by national statistical institutes in the SEEA-Water (see Appendix A). Different concepts, definitions, assumptions and data sources complicated this comparison. While PCR-GLOBWB applies general assumptions to countries and over time, and disaggregates to grid cell level, SEEA-Water is a bottom-up, data-based approach, collecting data from among other things registers and surveys. However, the comparisons showed relatively small differences for the Netherlands, but some larger differences for Botswana and Brazil. The main differences are in water use by the energy sector (probably due to cooling), in agriculture, and in the abstraction of groundwater (Brazil and Botswana).

3 Valuation of water

3.1 Methods

The previous sections focused on the direct consumptive water use of the domestic, industrial, livestock and irrigation sectors (q in Eq. 3). In this section, we also focus on other, indirect (non-consumptive) water uses, which include recreation and tourism, hydropower, waste assimilation, inland fisheries, navigation, aquatic biodiversity, and spiritual and cultural. In the water valuation literature, a variety of different methods have been proposed to derive monetary values for these, for an overview, see Brouwer *et al.* (2009). Textbox 1 summarizes the most prevalent methods. Which one is the most appropriate, depends on the required value concept, the water use under consideration, as well as the availability of data - see the discussion in the remainder of this chapter.

Textbox 1: Water Valuation Methods

1. *Resource rent*. The resource rent is the value which remains after costs (for intermediate consumption, human capital (labour) and produced capital inputs) are subtracted from revenues. This is assumed to be the reward for natural capital. In the CWON 2018, this approach has been used to value many natural capital stocks such as energy and mineral resources, forest timber resources, and agricultural land. The resource rent methodology assumes perfect markets in which all production factors (labour, capital and natural resources) get the rents according to their marginal contribution. However, when it comes to natural capital stocks, market conditions often do not hold. Water is usually supplied by (semi-) public utilities where prices are set by governments and shortfalls are subsidized.

2. *Contingent valuation method*. Contingent valuation is based on welfare economic theory which uses willingness-to-pay (WTP) or willingness-to-accept (WTA) methods as a basis for valuation. WTP indicates the wellbeing individuals derive from a good or service and can be estimated on the basis of surveys. WTP can be used to estimate marginal values of incremental freshwater supply, but it cannot be used to provide a total value of water for human consumption, simply because the value of the first litres of water per day for drinking, cooking and hygiene is infinitely high.

3. *Replacement cost method*. This method values goods or services on the basis of its (least cost) alternative. For example, for valuing the consumption of water from a freshwater resource, the replacement cost would consider the cost of the alternatives desalinization of seawater, rainwater harvesting or wastewater reuse.

4. *Hedonic Pricing Method*. This method attributes the value of an asset to its different characteristics. For example, on the basis of the price differential between irrigated and rainfed cropland, the value of irrigation water can be determined.

5. *Opportunity cost*. These are equal to the benefits forgone by not allocating an additional unit of water to its most economically productive use at a specific location in a river basin at a specific moment in time.

3.2 Domestic water use

In PCR-GLOBWB, domestic water use (estimated at on average 310 km^3 per year[7]) is the water used by households, small businesses and the government.[8] In developed countries, most of this water is delivered by public water utilities through a piped network system. In developing countries, the coverage of the piped network is far from complete and many households rely on other sources, such as wells, ponds and rivers, which are often unsafe to drink without treatment and/or require time to fetch.

As has been mentioned in the introduction, due to government regulation of tariffs and subsidies for water, the resource rent of utilities is often zero or negative, resulting in a zero or negative value of water. In several countries, therefore, the replacement cost method has been used to value freshwater resources in the context of SEEA. In case the valuation would consider one specific water resource (e.g. groundwater), the replacement cost could consider using the cost of the nearest substitute for the valuation, which could be another freshwater resource (e.g. surface water). However, since CWON attempts to include the aggregated value of all freshwater resources, the replacement cost method should consider the cost of the alternative, non-freshwater resource, such as desalinated seawater. Using replacement cost, the value of the freshwater resource should be based on the cost-difference between the current system based on freshwater, and a system based on desalinated seawater. There are different databases that might be used for this approach. The first one is the IBNET database of water supply utilities worldwide, which includes data on different aspects such as costs, revenues and service levels. In 2010, the IBNET database covered 1861 water utilities serving nearly 513 million people with water in more than 12 thousand cities and towns; this is equivalent to approximately 14 percent of the world population with access to piped water (World Bank, 2014). The data can be accessed through a web-interface[9] where data of utilities is converted to average country level data. However, the operating costs in IBNET do not include the cost of fixed assets (investments, depreciation), nor the financing costs (interest, repayments), which are sometimes financed by others (e.g., governments). Hence, IBNET does not provide the full (financial) cost of piped domestic water supply systems, necessary as input to estimate cost difference of the two different systems. For the cost of desalination, there are different sources and databases. The cost is likely to be in the range of US$ 0.5 and 2.5 per m^3 see World Bank, 2019; Edens & Graveland, 2014; Zhou & Tol, 2005).

3.3 Industrial water use

In PCR-GLOBWB, industrial water use refers to all water used by major industries (mining, manufacturing, energy companies etc.); it is either supplied by the public water supply network, or companies extract the water directly from surface or groundwater. An important distinction is between freshwater withdrawal (global 820 km^3 per year) and actual freshwater consumption (global 220 km^3 per year[10]).

[7] 85% of 368 km^3.
[8] We note that the categories of direct water uses and the definitions of these uses do not fully match between the water databases, models, and those which are most desirable from the viewpoint of valuation according to the principles in the SNA/SEEA. For example, domestic (municipal) water use in AQUASTAT includes water for households, small industries and government connected to the piped water network, while domestic water in PCR-GLOBWB includes also water for households not connected to the network. The SEEA has water accounts where water use is allocated to those different users.
[9] https://database.ib-net.org
[10] 85% of 258 km^3.

The consumptive water use of industries can be used on the basis of the replacement cost, similar as for domestic water use. A large part of the freshwater withdrawal is for cooling, which does not only generate economic benefits but also considerable environmental cost, which may be considerable and are difficult to assess. For this reason, we propose not to value this part of the industrial water use at this time.

3.4 Livestock

Water for livestock (global 14 km^3 per year[11]) covers all consumptive (drinking) water use of livestock, which is only a very small amount compared to domestic and industrial water use. We propose to value this on the basis of the cost of desalination, similar as for domestic water and industrial water use.

3.5 Irrigation

On a global level, rainfed agriculture covers 80% of the cultivated land area and irrigated agriculture 20%, while irrigated agriculture accounts for 40% of global food production (UNESCO, 2014) - which clearly shows the benefit of irrigation (it roughly doubles the production). The net use for irrigation water is on average 2950 km^3 per year.[12]

Two different methods may be considered to value irrigation water: (a) opportunity cost and (b) resource rent. Estimates of the opportunity cost of water (OCW) for irrigation can be found in the literature. Bierkens *et al.* (2019) provide an overview of this literature and contribute new estimates of this OCW on the basis of model data. The OCW differs between crops and countries and ranges between US$ 0.01 and US$ 0.25 per m^3, with most estimated values smaller than US$ 0.10 per m^3.

The resource rent method to value irrigation water can follow the approach taken in the current CWON to value Agricultural Land, albeit now a distinction should be made between the values for rainfed and agricultural crop land. The difference between the resource rent for rainfed and agricultural land can then be used to value irrigation water. As is the case for Agricultural Land, the data on crop prices, yield and cost can be found in FAOSTAT.

3.6 Hydropower

In 2015, hydropower generated 4.1 million GWh, which is almost 17% of the world's total electricity and 70% of all renewable electricity.[13] The value of water used for hydropower can be estimated on the basis of (a) the basis of replacement cost of hydropower with the least cost alternative renewable energy resource, or (b) resource rent. For the replacement cost, the International Renewable Energy Agency (IRENA) collects data on different renewable energy resources. Globally, hydroelectric power is the cheapest source of renewable energy, with an average global cost of US$ 0.047 per kilowatt hour (kWh) (2019). Since 2010, the unit cost is slightly increasing due to an increasing number of projects with more expensive development conditions, especially in Asia. The global average cost per kWh for other renewable resources range from US$ 0.053 (for onshore wind) to US$ 0.182 (for concentrated solar power). The alternative method, resource rent, is currently being worked out in the context of the valuation of renewable energy resources for the CWON 2020.

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[11] 85% of 16 km^3.
[12] 85% of 3476 km^3.
[13] https://en.wikipedia.org/wiki/Hydroelectricity

3.7 Inland fisheries

Like marine fishing, the resource rent method seems the most appropriate method to value inland fisheries. A good resource to start valuing inland fisheries is a 2018 report by FAO (FAO 2018). This report mentions an inland fishery catch of 11 million tons in 2015, representing 12 percent of total global capture fishery production. Seventeen countries produce 80 percent of this catch. Small-scale inland fisheries catch tends to be directed for local human consumption and play an important direct role in food security. The global gross value added of inland fishing is estimated by FAO at some US$ 100 billion annually. This gross value added of inland fishing has to be decomposed in a return to labour, capital and water/fish. The derivation of the resource rent needs further studies and literature review and may be expected to be challenging.

FAO's FishstatJ[14] contains country specific data on inland fish catch.

3.8 Navigation

According to the CIA, there are around 649 thousand kilometers of navigable waterways in the world.[15] Important countries are China (17% of global length), Russia (16%), Brazil (8%), Europe (8%) Vietnam (7%) and the USA (6%). The most complete dataset on inland water transport is from the OECD with data for 53 countries.[16] This data shows that inland water transport has been steadily increasing from 1.4 trillion tonkilometer (tkm) in 2000 to 4.5 trillion tkm in 2016. The value of inland waterways can be based on the replacement cost, i.e. by comparing the cost per tkm of this mode with the cost of alternative transport modes. Schade *et al.* (2006) have collected data on the average per unit cost of different modes of transport for Europe and the US, which could be used as a starting point in the valuation.

3.9 Other water uses

Several other water uses were considered but have not been included in the roadmap:

- Recreation and tourism: the types of ecosystem benefits freshwater bodies provide for recreational benefits (partly) overlaps with ecosystem services provided by forests and protected areas, which are already included in the CWON;
- Waste assimilating: waste is often disposed in water and as such water provides a 'free' service to households, businesses and industries. Consumption of contaminated water at the same time leads to various diseases and environmental problems and many countries have launched programs to increase water quality, sometimes at considerable cost. Since using water as a dump for waste does not only generate benefits but also cost, we recommend not to value this service that water bodies provide at this stage;
- (Aquatic) biodiversity: valuing biodiversity in monetary terms remains a difficult and controversial issue (it requires non-use values) and is not practiced in many countries. It is also not included in the current CWON as part of the value of forests, protected areas or other assets. For this reason, it is also excluded from this roadmap;
- Spiritual and cultural value: although water can also have religious or cultural meaning which is ascribed to a specific water body or the resource itself, it is not recommended to include this in the roadmap. In general, the CWON does not include those types of values, except when they are represented in market prices of land or assets near water.

[14] http://www.fao.org/fishery/statistics/software/fishstatj/en
[15] https://www.cia.gov/library/publications/the-world-factbook/fields/386rank.html
[16] https://stats.oecd.org/Index.aspx?DataSetCode=ITF_GOODS_TRANSPORT

3.10 Indicative global asset value of freshwater

We conducted a first exemplary rough estimate of the global asset value of water, which included the values of water for domestic, industry, livestock, irrigation, hydropower and navigation use (see the online background document), and in which we assumed a sustainable use of the water resource (i.e., lifetime *T* of 100 years) (Appendix B). The exercise revealed an asset value of freshwater resources of some US$ 19 - 35 trillion, which is roughly comparable to the values for Forests and Protected Areas (US$ 18 trillion), Agricultural Land (US$ 40 trillion) or Fossil Fuels (US$ 39 trillion) (CWON, 2018). As a percentage of total global wealth, the estimated value of water is relatively small (2 - 3%). About equal values were found for domestic, industry, irrigation and navigation, whereas the values for livestock and hydropower appear to be considerably less.

4 Roadmap for valuing water

A roadmap for valuing water in the CWON includes the following 6 main points:

1 *Water uses*. We advise to start with the following water uses: domestic, industrial and inland fisheries. Livestock, irrigation, hydropower, and tourism and recreation are already (at least partially) included the CWON under different natural capital stocks. It should be assessed to what extent their values can be ascribed to water. For example, in the current CWON, the value of cropland is a function of the land characteristics including the hydrological conditions and a method could be explored to split the resource rent of cropland in a land and water component. Global data on navigation appears to be scarce and incomplete (the OECD has data for 53 OECD countries); hence navigation is difficult to include as part of the value of water in CWON.
2 *Regionalization*. Water scarcity, prices, use, quality and sustainability can vary significantly within a country. Calculating the value of freshwater resources using statistics on a national level is therefore imprecise and risky, as it does not confront local water demand with local availability and therewith misses important scarcity, price and cost effects. Valuing water should therefore start at lower spatial levels than that of countries, and CWON can present the national aggregates.
3 *Sustainability*. An important concern in the asset valuation is to assess whether water resources are sustainably used, or at risk of depletion. This is indicated by the variable T, the time over which the asset is expected to generate benefits, which is based on the volume of the water resource, Q, its abstraction, q, and replenishment, z. If possible, the assessment should be done for water resources individually. The result should be provided at the country level but the transboundary character of shared fresh water stocks and flows should also be considered.
4 *Water valuation database*. We have identified a couple of databases which might serve as a solid basis for valuation. However, databases such as IB-NET require additional manipulation to calculate full costs, and proxies are needed for uses and countries that are not included in the database.
5 *Water quality*. Measures to improve the quality of freshwater resources, increase the asset value of the resource by reducing the cost of water supply, c. Although this has not been explored in this chapter, we recommend further studies how to include water quality in the valuation of freshwater resources;
6 *Use and extend a global hydrological model to value water*. The available national databases can be used to value water, as long as sustainability is assumed. The use of a global hydrological water model has a number of distinct advantages over the databases, which include gap filling, scenario analysis and sustainability analysis. Hydrological models downscale part of the national data and can provide local asset values, which after aggregation provide national values for the inclusion in CWON. However, it is also recommended to further validate and align the results from these global hydrological models with national water statistics. More in-depth analyses are needed, including a thorough review of definitions, data recording and reliability, and maybe inter-model comparisons.

5 References

Alcamo, J., Döll, P., Henrichs, T. Kaspar, F., Lehner, B., Rösch, T. & Siebert, S. (2003), Global estimation of water withdrawals and availability under current and “business as usual” conditions. Hydrol. Sci. J. 48(3), 339–348.

Bierkens, M. F. P., Reinhard, S., de Bruijn, J. A., Veninga, W., & Wada, Y. (2019). The shadow price of irrigation water in major groundwater-depleting countries. Water Resources Research, 55, 4266–4287. https://doi.org/10.1029/2018WR023086

de Graaf, I. E. M., Sutanudjaja, E. H., van Beek, L. P. H., and Bierkens, M. F. P.: A high-resolution global-scale groundwater model, Hydrol. Earth Syst. Sci., 19, 823–837, https://doi.org/10.5194/hess-19-823-2015, 2015.

Edens, Bram and Cor Graveland (2014), Experimental valuation of Dutch water resources according to SNA and SEEA. Water Resources and Economics Volume 7, September 2014, Pages 66-81.

Falkenmark M. (1986), Fresh water: Time for a modified approach. Ambio. 1986;15:192–200.

Fang, Y., & Jawitz, J.W. The evolution of human population distance to water in the USA from 1790 to 2010. Nat Commun 10, 430 (2019). https://doi.org/10.1038/s41467-019-08366-z

FAO (2018). Review of the state of the world fishery resources: inland fisheries http://www.fao.org/3/ca0388en/CA0388EN.pdf

Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., and Alcamo, J.: Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study, Global Environ. Change, 23, 144–156, https://doi.org/10.1016/j.gloenvcha.2012.10.018, 2013.

Gleeson, T., J. VanderSteen, A. A. Sophocleous, M. Taniguchi, W. M. Alley, D. M. Allen, a nd Y. Zhou (2010), Commentary: Groundwater sustainability strategies, Nat. Geosci., 3, 378–379, doi:10.1038/ngeo881.

Hanasaki, N., Yoshikawa, S., Pokhrel, Y., and Kanae, S.: A global hydrological simulation to specify the sources of water used by humans, Hydrol. Earth Syst. Sci., 22, 789–817, https://doi.org/10.5194/hess-22-789-2018, 2018.

Liang, X., Lettenmaier, D. P., Wood, E. F., and Burges, S. J. (1994), A simple hydrologically based model of land surface water and energy fluxes for general circulation models, *J. Geophys. Res.*, 99(D7), 14415– 14428, doi:10.1029/94JD00483.

Lindström, G., Pers, C., Rosberg, J., Strömqvist, J. & Arheimer, B. (2010). Development and testing of the HYPE (Hydrological Predictions for the Environment) water quality model for different spatial scales. Hydrology Research 41.3–4, 295-319.

Roy Brouwer, David Barton, Ian Bateman, Luke Brander, Stavros Georgiou, Julia Martín-Ortega, Stale Navrud, Manuel Pulido-Velazquez, Marije Schaafsma, Alfred Wagtendonk, 2009. Economic Valuation of Environmental and Resource Costs and Benefits in the Water Framework Directive: Technical Guidelines for Practitioners. AquaMoney

Schade W, Doll C, Maibach M, Peter M, Crespo F, Carvalho D, Caiado G, Conti M, Lilico A, Afraz N (2006): COMPETE Final Report: Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States. Funded by European Commission – DG TREN. Karlsruhe, Germany.

Stehfest, E., van Vuuren, D.P., Bouwman, L., Kram, T., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Müller, C., and A. Prins (2014). IMAGE 3.0, PBL.

Straatsma, M., Droogers, P., Hunink, J., Berendrecht, W., Buitink, J., Buytaert, W., … Bierkens, M. F. P. (2020). Global to regional scale evaluation of adaptation measures to reduce the future water gap. Environmental Modelling & Software, 124, 104578. https://doi.org/10.1016/j.envsoft.2019.104578

Sutanudjaja, E. H., van Beek, R., Wanders, N., Wada, Y., Bosmans, J. H. C., Drost, N., van der Ent, R. J., de Graaf, I. E. M., Hoch, J. M., de Jong, K., Karssenberg, D., López López, P., Peßenteiner, S., Schmitz, O., Straatsma, M. W., Vannametee, E., Wisser, D., and Bierkens, M. F. P. (2018): PCR-GLOBWB 2: a 5 arcmin global hydrological and water resources model, Geosci. Model Dev., 11, 2429–2453, https://doi.org/10.5194/gmd-11-2429-2018.

Thomas, B.F., Famiglietti, J.S. Identifying Climate-Induced Groundwater Depletion in GRACE Observations. Sci Rep 9, 4124 (2019). https://doi.org/10.1038/s41598-019-40155-y

Turpie, J.K., Letley, G., Schmidt, K., Weiss, J., O'Farrell, P.1 and Jewitt, D. (2020), Towards a method for accounting for ecosystem services and asset value: Pilot accounts for KwaZulu-Natal, South Africa, 2005-2011. https://seea.un.org/sites/seea.un.org/files/files/documents/2020/Jul/ncaves_kzn_pilot_-_final_report_june_2020.pdf

Van Der Knijff, J.M., Younis, J., and DeRoo, A.P.J.: LISFLOOD: a GIS-based distributed model for river basin scale water balance and flood simulation, Int. J. Geogr. Inf. Sci., 24, 189–212, https://doi.org/10.1080/13658810802549154, 2010.

van Dijk, A. I. J. M., Renzullo, L. J., Wada, Y., and Tregoning, P.: A global water cycle reanalysis (2003–2012) merging satellite gravimetry and altimetry observations with a hydrological multi-model ensemble, Hydrol. Earth Syst. Sci., 18, 2955–2973, https://doi.org/10.5194/hess-18-2955-2014, 2014.

Weedon, G. P., Balsamo, G., Bellouin, N., Gomes, S., Best, M. J., and Viterbo, P. (2014), The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data, Water Resour. Res., 50, 7505– 7514, doi:10.1002/2014WR015638

World Bank (2014). The IBNET Water Supply and Sanitation Blue Book 2014: The International Benchmarking Network for Water and Sanitation Utilities Databook. Alexander Danilenko, Caroline van den Berg, Berta Macheve, L. Joe Moffitt (Eds.)

World Bank (2019). The Role of Desalination in an Increasingly Water-Scarce World. World Bank, Washington, DC

World Bank, 2018. The Changing Wealth of Nations 2018. Building a Sustainable Future. Glenn-Marie Lange, Quentin Wodon and Kevin Carey (Eds.)

Zhou, Y and Richard S. J. Tol (2005). Evaluating the costs of desalination and water transport. doi.org/10.1029/2004WR003749

A Comparison of model data from PCR-GLOBWB2 with SEEA-Water for selected countries

In this Appendix A we compare outcomes of the PCR-GLOBWB model on freshwater with reported data (in physical units) compiled by statisticians in the so-called Water accounts based on the System of Environmental-Economic Accounts (SEEA-Water). Such a comparison may provide more insight into the value and validation of the two approaches.

What is SEEA-Water?
The System of Environmental-Economic Accounts (SEEA) central framework is an internationally agreed system producing internationally comparable statistics and accounts on various environmental themes such as agriculture, air emissions, material flows, energy, and water. The SEEA is consistent with the System of National Accounts (SNA). The water accounts, a subsystem of the SEEA (SEEA-Water), provide hydrological and water related economic statistics across sectors. It brings a set of accounts consistent with each other:

- Accounts of physical flows (supply and use) of water between environment and economy, i.e. abstraction of water from the environment, flows within the economy, and return flows to environment. These flows can also be linked to water emission accounts, that provide data on emissions of pollutants to (waste) water as result of economic activities.
- Accounts of physical assets of water, i.e. stocks and their depletion over the accounting period, with links to abstraction and consumption of water by the economy.
- Economic accounts with among others water products, cost of water use and supply, and water related financing.[17]

As of 2020, more than 90 countries have compiled SEEA accounts on varying environmental themes, in varying degrees of completeness due to data gaps (accounting periods, sector detail information etc.) and policy priorities.[18] According to an official assessment by UNSD in 2017, 25 of these countries had compiled water accounts (see Appendix A.1). By that time, nearly 50 more countries were planning to do so.[19] By 2020, some more countries had indeed implemented water accounts.[20]

What is compared between SEEA-Water and PCR-GLOBWB?
We selected three countries that compiled SEEA-Water accounts for comparison with the PCR-GLOBWB model outcomes. The three countries are on different continents: The Netherlands, Botswana, and Brazil. The Netherlands have much experience with SEEA compared to the last two countries (see Appendix A.2 for more detail).

[17] The statistics provided by SEEA-Water can be also applied to ecosystem accounts, with water as an asset and as a service), and to some of the indicators in SDG 6 on water. For further information on SEEA-Water, see https://seea.un.org/content/seea-water.
[18] Source: https://seea.un.org/content/frequently-asked-questions#_How_many_countries.
[19] Source : Table 2 and Table 4, in: UNCEEA (2018), "*Global Assessment of Environmental-Economic Accounting and Supporting Statistics 2017*", https://unstats.un.org/unsd/statcom/49th-session/documents/BG-Item3h-2017-Global-Assessment-of-Environmental-Economic-Accounting-E.pdf.
[20] Such as Uganda. See https://seea.un.org/content/knowledge-base.

For comparison with the PCR-GLOBWB model variables, we focus on the physical flows on water use by households, agriculture and business sectors, and the abstraction of surface water and groundwater from the environment. More precisely, we focus on the gross water use by sector and total abstraction from environment (green cells) in the physical use table as shown in a simplified version in Figure A.1 below.[21]

Figure A.1 Physical use table SEEA Water

		A Agriculture, forestry and fishing		B Mining and quarrying	C Manufacturing	D Energy supply		E Water supply	F Construction	G - U Other economic sectors	Households	Rest of World	Total
		Irrigation	Livestock			Electricity	Gas etc						
Abstraction from environment	Surface water												
	Ground water												
	Other												
	1. Total												
Within the economy	2. Water use from other economic sectors												
	Total use of water (1 +2)												

We compare gross water use, as net water use is more complicated (or data are missing, such as is the case for the Netherlands). Furthermore, the data differ across the countries in rows (e.g. reservoirs in Botswana, rainwater in Brazil) and columns (e.g. various mining industries in Botswana). However, we compare on higher aggregation levels. For instance, reservoirs are part of surface water, which is compared across the countries; and the various mining industries are part of the total of the sector mining and quarrying, which is compared), for clarity / for ease of comparison. Further note that PCR-GLOBWB models fresh water, while SEEA-Water data may contain also salt water (sea or coastal water, in surface water). The data from the PCR-GLOBWB model are an annual average covering the period 2000-2014, for each model variable. The data from SEEA-Water contain time series, referring to different periods for the different countries. We calculated an annual average for each variable in the SEEA-Water where data are available in the period 2000-2014. This is 2003-2014 for The Netherlands, 2012-2014 for Botswana and 2013-2014 for Brazil.

Results from the comparison of SEEA-Water and PCR-GLOBWB

The comparison of gross water use (by sector) and abstraction according to the SEEA-Water with gross water demand and abstraction in the PCR-GLOBWB model show relatively small differences for the Netherlands, but some large differences for Botswana and Brazil (see Appendix A.3).

Netherlands

Considering that the two approaches (SEEA-Water and PCR-GLOBWB) have very different starting points (data, assumptions etc.), and the data from Statistics Netherlands meet a certain level of quality, the small differences for the Netherlands may be an indication of the quality of the model outcomes for this country. Water demand in PCR-GLOBWB is based on AQUASTAT and UN data, which are of good quality for the Netherlands and other Western European countries.

[21] Economic activities are classified according to the ISIC (Rev.4). As Brazil accounts for Construction (ISIC F) together with Manufacturing (ISIC C), we take Construction (F) also into account for the other two countries. The volume of water use by this sector is relatively small. Further, the other economic sectors ISIC G to U are not taken into account in the comparison as their water use is relatively small

The main differences for the Netherlands are in industry water use and in abstraction of surface water. Within the industry sector, it is mainly the energy sector (ISIC D) that uses much water, mainly for cooling purposes. If we exclude this sector, the difference between SEEA data and model outcomes decreases substantially. Part of the water abstracted from surface water is coastal water (of which most is used by the energy sector for cooling). If we exclude salt water, and focus on fresh water (as the PCR model does), the difference between SEEA and PCR is smaller still.

Botswana

In contrast to The Netherlands, Botswana's energy sector plays a minor role in water use. But in total ISIC sectors B to F nearly 5 times more water according to SEEA than the model predicts. Part of the observed differences between SEEA-Water data and the PCR-GLOBWB model outcomes for Botswana might come from the fact that data from AQUASTAT are missing or not up to date for middle or lower income countries.

Agriculture, particularly livestock, uses far more in SEEA-Water than in PCR-GLOBWB (12 times more). The PCR-GLOBWB model applies only water consumption for livestock, and differences in data sources (number of animals, water volume per head) may explain the difference with SEEA-Water data on agriculture. On the other hand, household gross water use in the SEEA-Water for Botswana is only half the volume predicted by PCR-GLOBWB. Detailed data on water infrastructure are not available in the PCR-GLOBWB model.
The large difference for Botswana's abstraction of groundwater (in SEEA 56 times larger than in the model) is also noticeable. Note that the classification of abstracted water into surface water and groundwater is based on general assumptions applied at country level, whereas SEEA-Water accounts are based on collected register or survey data.

Brazil

For Brazil, the differences between SEEA-Water and PCR-GLOBWB are the largest of the countries considered (Netherlands, Botswana, Brazil). Characteristic for Brazil is that the energy sector (ISIC D) does play a major role in the industry's use of water. Including this energy sector, water use according to SEEA is more than 300 times larger than according to the PCR-GLOBWB model. If we exclude the energy sector, this factor decreases to near 7. It is known that Brazil uses relatively much hydropower. SEEA-Water records the use of water for hydroelectric power generation, whereas PCR-GLOBWB does not. This probably explains much of the large difference.

Just like Botswana, gross domestic water use in Brazil is nearly half that of the amount specified for PCR-GLOBWB, and agriculture is using more, up to 16 times. And also like Botswana, but even more pronounced, the difference is large for groundwater, with a factor of more than 300. There is also a noticeable difference for surface water but somewhat smaller.

A.1 Water accounts: regularity of account compilation (UNSD assessment 2017)

25 countries have compiled water accounts since 2008	Number of times compiled	7 2008	6 2009	9 2010	12 2011	12 2012	14 2013	14 2014	15 2015	6 2016	3 2017
MEXICO	9	■	■	■	■	■	■	■	■	■	
GEORGIA	9		■	■	■	■	■	■	■	■	■
COLOMBIA	8	■	■	■	■	■	■	■	■		
THE NETHERLANDS	7	■	■	■	■	■	■	■			
AUSTRALIA	7			■	■	■	■	■	■	■	
CANADA	6	■	■	■	■	■	■				
DENMARK	6			■	■	■	■	■	■		
BOSNIA AND HERZEGOVINA	5					■	■	■	■	■	
IRELAND	5			■	■	■	■	■			
SAMOA	5				■	■	■	■	■		
BOTSWANA	4					■	■	■	■		
FIJI	4						■	■	■	■	
MAURITIUS	4				■		■	■	■		
SPAIN	3	■	■	■							
COSTA RICA	3					■	■	■			
PALAU	3							■	■	■	
NEW ZEALAND	2				■						■
ISRAEL	1	■									
TURKEY	1	■									
ARMENIA	1								■		
BRAZIL	1										■
NAMIBIA	1								■		
P.R.CHINA	1								■		
TAJIKISTAN	1								■		
UNITED KINGDOM	1				■						

Source: Table A.1, Water accounts: regularity of account compilation, in: Statistics South-Africa (2018), "Global Assessment of Environmental-Economic Accounting and Supporting Statistics, Additional analysis, Version 3.0", https://seea.un.org/sites/seea.un.org/files/area_d_gap_analysis_v3.0.pdf.

A.2 SEEA-Water for The Netherlands, Botswana, and Brazil

The Netherlands

The Netherlands are one of the most experienced countries in compiling SEEA accounts, among which water accounts. Their water data go back to the 1990s, but consistent time series within SEEA-Water start in 2003, with the most recent year 2018. However, these Water accounts are not complete yet, e.g. (part of the) return flows are still missing.[22] The data available at Statline, the national databank of Statistics Netherlands, comprise fresh water as well as salt water, while requested data delivered to Eurostat exclude salt water.

Data are available at:

- All types (fresh and salt) water: http://opendata.cbs.nl/statline/#/CBS/nl/dataset/82883NED/table?dl=3B958
- Fresh water only: https://ec.europa.eu/eurostat/data/database Tables *env_wat_abs* and *env_wat_cat*

[22] Recently, an Eurostat grant was applied for to fill this data gap.

Botswana
In 2012, Botswana (Department of Water Affairs) started with compiling water accounts within a WAVES initiative in partnership with the World Bank. In december 2017, Botswana published her fourth and last report on SEEA-Water. After then no update was provided for, at least not in English. The present data available run from 2012-2013 to 2015-2016. Botswana still focuses on physical flow accounts (use and supply) only. In her 2017 report, Botswana announced that asset accounts and monetary accounts would be released later. Data are available at https://seea.un.org/content/botswana-water-accounting-report-2015-2016

Brazil
Of the three countries selected, Brazil is the least experienced in Water accounting. In 2020, the IBGE (Brazil Institute for Geography and Statistics) published for the second time SEEA-Water accounts covering the period from 2013 to 2017, with data for Brazil as a whole and some major regions. The Water accounts are nevertheless very complete. The IBGE compiled these accounts together with the national water agency, with the support from Germany and the European Union (Environment Department).
Data are available (in Portugese) at https://www.ibge.gov.br/en/statistics/economic/national-accounts/20510-environmental-economic-accounting-for-water-brazil.html

A.3 Comparison PCR-GLOBWB and SEEA-Water The Netherlands, Botswana, and Brazil

The Netherlands						
						Ratio
PCR-GLOBWB model annual average 2000-2014			**Wateraccounts, annual average 2003-2014***			**SEEA/PCR**
	mcm			*mcm*		
gross water demand households, agriculture, industry	*6997,0*		total gross water use	16312,2		2,33
			households, agriculture, industry	16214,9		2,32
			households, agriculture, industry excl ISIC D Energy	6415,1		0,92
net_domestic_demand	227,4					
gross_domestic_demand	637,9		households	790,7		1,24
net_industrial_demand	1291,5					
gross_industrial_demand	6215,0		industry ISIC B to F	15277,7		2,46
			B Mining and quarrying	4,5		
			C Manufacturing	3687,7		
			D Energy	9799,8		
			E Water	1782,8		
			F Construction	2,9		
			industry B to F excl. D Energy	*5477,9*		0,88
livestock_demand	3,5					
irrigation_demand	140,6					
total livestock + irrigation	*144,1*		total agriculture	146,5		1,02
runoff	13075,4					
baseflow	9972,1					
desalination_abstraction	0,0					
surface_water_abstraction	4129,3		surface water (fresh and salt water)	14210,9		3,44
			*surface water excl salt water ****	10823,3		2,62
nonfossil_groundwater_abstraction	926,8					
fossil_groundwater_abstraction	1,2					
total groundwater	*928,0*		groundwater	1011,9		1,09
			* average of years 2003 - 2014			

Botswana						
						Ratio
PCR-GLOBWB model annual average 2000-2014			**Water accounts, annual average 2012-2014***			**SEEA/PCR**
	mcm			*mcm*		
gross water demand households, agriculture, industry	*106,4*		total gross water use	267,1		2,51
			households, agriculture, industry	244,4		2,30
			households, agriculture, industry excl ISIC D Energy	244,3		2,30
net_domestic_demand	45,6					
gross_domestic_demand	72,8		households	40,0		0,55
net_industrial_demand	9,9					
gross_industrial_demand	28,2		industry ISIC B to F	136,9		4,85
			B Mining and quarrying	41,3		
			C Manufacturing	2,5		
			D Energy	0,1		
			E Water	92,6		
			F Construction	0,4		
			industry B to F excl. D Energy	136,8		4,85
livestock_demand	0,5		livestock	47,0		96,60
irrigation_demand	4,9		irrigation total use	20,5		4,19
total livestock + irrigation	*5,4*		*total agriculture*	67,5		12,53
runoff	6260,9					
baseflow	1064,8					
desalination_abstraction	0,0					
surface_water_abstraction	30,8		surface water (reservoirs + rivers)	85,9		2,79
nonfossil_groundwater_abstraction	1,7					
fossil_groundwater_abstraction	0,1					
total groundwater	*1,8*		groundwater	101,4		56,97
			* average of years 2012-2013, 2013-2014 and 2014-2015			

Brazil						
						Ratio
PCR-GLOBWB model annual average 2000-2014			**Water accounts, annual average 2013-2014***			**SEEA/PCR**
	mcm			*mcm*		
gross water demand households, agriculture, industry	*58488,9*		total gross water use	3455285,0		59,08
			households, agriculture, industry	3453278,1		59,04
			households, agriculture, industry excl ISIC D Energy	654775,8		11,19
net_domestic_demand	6629,5					
gross_domestic_demand	14405,3		households	8854,9		0,61
net_industrial_demand	3050,4					
gross_industrial_demand	8698,8		industry ISIC B to F **	2862400,3		329,06
			B Mining and quarrying	978,8		
			C Manufacturing and F Construction	6788,4		
			D Energy	2798502,3		
			E Water	56130,9		
			industry B to F excl. D Energy	63898,0		7,35
livestock_demand	3294,9					
irrigation_demand	32089,9					
total livestock + irrigation	*35384,8*		total agriculture	582022,9		16,45
runoff	7064531,7					
baseflow	3248511,8					
desalination_abstraction	0,0					
surface_water_abstraction	56311,8		surface water	2846530,9		50,55
nonfossil_groundwater_abstraction	1674,6					
fossil_groundwater_abstraction	13,8					
total groundwater	*1688,4*		groundwater and soil water	555306,1		328,90
			* average of years 2013 and 2014			
			** F (construction) is included in sector Manufacturing and Construction, not separable			

B Indicative global value of water

In this Appendix, we provide a preliminary, indicative global asset value for freshwater resources, based on the information presented in the main text and some additional bold assumptions. By comparing this asset value to the values of other assets reported in the CWON 2018, a first impression of the value of water is derived, as well as of the different value components. The global value should be interpreted with caution, since assumptions and methods need further research and validation. For actual inclusion in the CWON, the values should be country specific and cover a longer time period.

The indicative global value is summarized in Table B.1. It is based on the following assumptions:

- Water volumes are the annual averages over 2000-2014;
- Domestic, industrial and livestock: replacement cost of water assumed at US$ 0.5 to 1.5 per m3.
- Irrigation: two alternative methods are included in the table, providing a range of values:
  - Resource rent: 20% of the resource rent of Agricultural Land, as reported in CWON 2018, is assumed to be attributable to irrigation water;
  - Opportunity cost: US$ 0.10 per m3 is assumed.
- Hydropower: two alternative methods are included in the table, providing a range of values:
  - Replacement cost: a global cost difference of US$ 0.02 per kWh is assumed between hydropower and the least cost renewable alternative for hydropower. The average remaining life time of the hydropower dams is assumed to be 15 years (i.e. 50% of 30 years (IRENA 2019)).
  - Resource rent: the next version of the CWON is expected to contain a separate scoping chapter with experimental results for renewable energy resources, including hydropower, on the basis of data from IRENA. A preview of the hydropower section indicates that for 15 countries, covering 70% of globally installed hydropower, the asset in 2017 is estimated to be some US$ 0.858 trillion. This is equivalent to US$ 1.2 trillion for 100% capacity, which is close to the value based on replacement cost (equivalent to US$ 0.9 trillion).
- Navigation:
  - Replacement cost. According to Schade *et al.* (2006), in Europe, the average cost of inland waterways is EUR 0.008 per tkm (2005 prices), while the cost of rail (the cheapest alternative) is EUR 0.110 per tkm. This suggests a value of inland waterways of EUR 0.102 per tkm. In the US, the average cost of inland waterways is EUR 0.006 per tkm , while the cost of rail (the cheapest alternative) is EUR 0.01 per km, which suggests a much lower value of inland waterways of EUR 0.004 per tkm. The global value is based on an assumed average of EUR 0.05 per tkm, infinite life time and 4% discount rate, the asset value of inland waterways in the 53 OECD countries would be assessed as 4.5 trillion x 0.05 /4% = EUR 5.6 trillion (2005 prices; approx. US$ 6 trillion in current prices).

For inland fisheries, FAO (2018) report a global annual value of US$ 100 billion annually, which is the reward for labour, capital and water/fish. An upper bound of the value of inland fisheries can be determined if we assume the entire rent for water/fish. Assuming a constant rent, this upper bound amount to US$ 2.5 trillion.

Table B.1: Indicate Global Asset Value of Freshwater Resources

User	Quantity per year	Method	Unit value or range	Contribution to Global Asset Value of Water (US$ Trillion)	Remark
Domestic	312.8 km^3 water	Replacement cost (Cost of desalinization)	US$ 0.5 – 1.5 per m^3	3.9 – 11.7	
Industrial	219.3 km^3water	Replacement cost (Cost of desalinization)	US$ 0.5 – 1.5 per m^3	2.7 – 8.2	Net demand only (no cooling etc.)
Livestock	13.6 km^3 water	Replacement cost (Cost of desalinization)	US$ 0.5 – 1.5 per m^3	0.2 – 0.5	For drinking purposes only
Irrigation	2955 km^3 water	Resource rent		5.3	20% of asset value of Agricultural Land in CWON 2018
		Opportunity cost	0.1 US$/$m^3$	7.4	
Recreation and Tourism				p.m.	
Hydropower	4.1 million GWh electricity	Replacement cost	0.02 US$/kWh	0.9	
		Resource rent		1.2	
Waste assimilation				p.m.	
Inland fishery	11 million ton fish	Resource rent		p.m.	Below US$ 2.5 trillion
Navigation	4.5 trillion tkm cargo	Replacement cost	0.05€/tkm	6.0	2016, OECD countries only
Aquatic Biodiversity				p.m.	
Spiritual and Cultural				p.m.	
Total				19 – 35 + 5 × p.m.	

p.m.: pro memoria (not valued in this context). The asset value is based on the average annual water use over the 2000-2014 period. Given the bold assumptions made, no corrections for different price levels of the input data has been done. Price levels range between 2010 and 2020 prices.

This “quick and dirty” estimate reveals a value of some US$ 19 – 35 trillion for the global asset value of freshwater resources. This value is roughly comparable to the 2014 values for Forests and Protected Areas (US$ 18 trillion), Agricultural Land (US$ 40 trillion) or Fossil Fuels (US$ 39 trillion), as reported in the CWON 2018, see Table 6. Roughly half of this value concerns the value of domestic, industrial and livestock water, valued on the basis of the (replacement) cost of desalinized seawater. As percentage of total global wealth (US$ 1143 trillion), the value of water remains relatively small (2 – 3%).

Table B.2: Global Wealth, by Type of Asset, 1995 and 2014 (Table copied from CWON 2018)

	1995		2014	
	Billion US$	**Percent**	**Billion US$**	**Percent**
Produced capital	164,781	24	303,548	27
Natural capital	52,457	8	107,427	9
Forests and protected areas	14,515	2	18,290	2
Agricultural land	25,859	4	39,890	3
Energy resources (fossil fuels)	11,087	2	39,094	3
Metals and minerals	997	<1	10,154	1
Human capital	475,594	69	736,854	64
Net foreign assets	−2,890	<1	−4,581	<1
Total wealth	689,942	100	1,143,249	100

Source: World Bank calculations.
Note: Figures are in constant 2014 US dollars at market exchange rates.

C List of issues for in the Roadmap

While preparing the Roadmap, we encountered several issues which need further attention:

A. Global issues

1. Validation. Although the reasons for using a global model like PCR-GLOBWB are convincing and clear, validating the results by comparing those with SEEA-W for a few selected countries has raised concerns. In general, the main concepts between PCR-GLOBWB and water statistics / accounts data align, but several issues have been identified that need more clarification, including the definition of water use by the electricity sector and water use for agriculture. More in-depth analyses are needed, including a thorough review of definitions, data recording and reliability, and maybe inter-model comparisons.
2. How to go from global model to countries. A model like PCR-GLOBWB provides data on a regular global grid of ~10 km resolution. Here we used a combination of catchment and administrative boundaries to aggregate to water provinces, these can be aggregated to country averages or totals. Yet, in these country totals, problems in very dry regions are smoothed. In addition water flows do not end at borders and there is a strong dependency between up-stream downstream countries as can for example be seen in the Nile basin in Egypt.
3. The volume of groundwater resources is unknown. It can be estimated using a global groundwater model like MODFLOW. In addition, satellite datasets like the data from the NASA mission of the Gravity Recovery and Climate Experiment (GRACE) provide information on water storage fluctuations, but its resolution (4 degrees) is too coarse to provide reasonable information. Satellite instruments and retrieval algorithms are improving and can in the future potentially provide a quantification of the absolute stocks.
4. As mentioned before, the valuation of water resources on the basis of total or average country data is tricky. It does not take the heterogeneity in a country with respect to water availability into account. While in one region of a country water may be scarce and the use of a water resource unsustainable, in another region water may be plenty available. Similarly the water availability is not constant throughout the year. In the dry season severe problems with water shortage may occur, but on an annual average basis these problems may not be visible as they are computationally compensated during the rainy season. Therefore the time horizon over which water is to be valued (see Eq. 1) cannot be used on the basis of annual country averages. One option to overcome this problem is to extend a model like PCR-GLOBWB to value the water resources on a daily or monthly time-step at the grid resolution. Results can be provided as valuation statistics that represent the local and temporal water shortages.
5. Time series. The analysis presented in this chapter, is based on the modelled average water use in the period 2000-2014. In CWON, time series should be included in order to monitor the development of asset values over time. This will show variation in the water asset values, partly due to climate variability. For example, in relative dry years, more irrigation water is used and hence the total value of irrigation water increases.
6. Sustainability and asset value. The asset values of freshwater resources in this chapter are based on annual values, assuming that those resources are used in a sustainable manner and can provide those benefits in future. Figure 3 has shown where water stress is high, and where unsustainable practices are likely to occur, like the depletion of water stocks. Assessing future scenarios can further indicate and quantify those risks. Where water resources (or stocks) are depleting, this should be reflected in the asset value by reducing the number of years on which asset values are based.

7. Water quality. Water quality is not fully included in this chapter. Current water use and water values may be assumed to be consistent with current water quality. Where water quality deteriorates, those uses may not be sustained in future, or at higher costs (hence lower values). Vice versa, where water quality improves, use may expand or at lower cost, and the value of freshwater resources increases. A future roadmap (perhaps a second version) should also attempt to address (changes in) water quality.
8. Separate values for groundwater and surface water. Consider the possibilities to estimate separate asset values for ground- and surface water resources. Both resources have different qualities and costs, and may yield different values. Valuing those resources separately provides additional insights in sustainable management and use.

B. Issues for specific use categories

Domestic water supply - IBNET

1. Full cost. Explore IBNET data to calculate/report the full cost of current water supply (not only the operational cost, as is currently the case). As the IBNET database does contain data on fixed assets and on debts, the full cost of piped water supply can likely be calculated on the level of the individual utilities.
2. Raw water source. Introduce a new indicator in IBNET to record the source of raw water (ground/surface/sea). Alternatively, estimate which raw water source is currently used on the basis of proxies (e.g., nearness of the utility to surface water, precipitation, perhaps altitude).
3. Understand costs of different systems. On the basis of the above, explore the cost-differences between water supply systems based on different sources for raw water.
4. Price effects. Where the current tariff is expected to increase considerable as a result of shifting from freshwater to desalinization, take into account the decline in demand before calculating the replacement cost.

Replacement cost/desalinization cost

5. Non-freshwater resources. Look into the importance of other potential resources for the replacement of freshwater resources than desalinization of seawater, e.g. rainwater harvesting, wastewater reuse.
6. Desalinization cost. Develop country specific estimates of the cost of water supply systems based on desalination or other non-freshwater resources.

Irrigation

7. Separate value of water from land. Separate the value of water which is now included in the value of Agricultural Land. This must be feasible on the basis of a comparable approach and data as has been used for the valuation of Agricultural Land in the 2018 CWON. The alternative method is to use the opportunity cost of water, as has been found by Bierkens et al. (2019).

Inland fisheries

8. Decide where to include. The World Bank should determine whether ‘Water’ is the appropriate place to include the value of inland fisheries. An alternative option could be to combine inland fisheries with marine fisheries.
9. Research the resource rent. Although there is some excellent data from FAO, it is a challenge to calculate resource rent for inland fisheries. Research is needed.

Hydropower

10. Decide where to include. We expect hydropower to be included in a separate chapter on renewable energy, and not to be part of freshwater resources. The indicative analysis indicates that the contribution to the value of water is likely to be modest on a global scale. This may be different on a country level.

Navigation

11. Try to find data. We find a significant contribution of navigable waterways to the value of water resources at a global level. Country specific data on volumes and costs are scarce, but we recommend further (literature) studies.

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